ADA

Single Common Powertrain Lubricant Development

INTERIM REPORT
TFLRF No. 418

By:
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Edwin A. Frame
Greg A. Hansen
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U.S. Army TARDEC Fuels and Lubricants Research Facility
Southwest Research Institute® (SwRI®)
San Antonio, TX

And:
Allen S. Comfort, US Army TARDEC

for
U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Contract No. W56HZV-09-C-0100 (WD01)

January 2012

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Contracted Author

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SwRI® Project No. 08.14734.01

Approved for public release: distribution unlimited

January 2012

Approved by:

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Research Facility (SwRI®)

REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
15-01-2012	Final Interim Report	March 2009 – January 2012

4. TITLE AND SUBTITLE
Single Common Powertrain Lubricant Development

5a. CONTRACT NUMBER
W56HZV-09-C-0100

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Brandt, Adam C; Frame, Edwin A; Warden, Robert W

5d. PROJECT NUMBER
SwRI 08.14734.01

5e. TASK NUMBER
WD 01

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army TARDEC Fuels and Lubricants Research Facility (SwRI®)
Southwest Research Institute®
P.O. Drawer 28510
San Antonio, TX 78228-0510

8. PERFORMING ORGANIZATION REPORT NUMBER
TFLRF No. 418

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Army RDECOM
U.S. Army TARDEC
Force Projection Technologies
Warren, MI 48397-5000

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The US Army has a desire to consolidate multiple MIL specification fluids into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems, and must be designed to operate in ambients ranging from low temperature arctic, to high temperature desert type conditions. The U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI) has aided TARDEC in the initial development of the SCPL. A request for experimental products was issued to industry, and 4 potential SCPL candidates were received and tested in military applications. Testing included high temperate endurance in the General Engine Products 6.5L(T) diesel engine to asses engine protection and oil performance at elevated temperatures, multiple industry standardized transmission tests (Allison C4, Caterpillar TO-4, John Deere JDQ) to asses frictional performance and driveline durability, and quantification of fuel consumption improvement over standard military oils through viscosity reduction in the SCPL. Two strong candidate lubricants were identified during testing, and have been jointly selected by TARDEC and SwRI for further revisions and testing.

15. SUBJECT TERMS

Single Common Powertrain Lubricant (SCPL), General Engine Products (GEP) 6.5L(T), High Temperature Oil Endurance, MIL-PRF-46167, MIL-PRF-2104, Candidate, Baseline, Total Acid Number, Total Base Number, Wear Metals, Oxidation, Fuel Economy, Pumping Losses, Transmission compatibility, Caterpillar TO-4, Allison C4, JDQ-96

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			19b. TELEPHONE NUMBER *(include area code)*
Unclassified	Unclassified	Unclassified	Unclassified	932	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

EXECUTIVE SUMMARY

The U.S. Army has a desire to consolidate multiple lubricant specifications into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems where MIL-PRF-2104 is currently used. The SCPL must be designed to operate in ambients ranging from low temperature arctic, to high temperature desert type conditions, representative of the wide range of potential military operating conditions.

This report will focus on the preliminary development of the SCPL from testing completed at the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI) in San Antonio Texas. Primary performance investigations of candidates supplied for SCPL testing included: chemical and physical analysis to determine fit for purpose, high temperature endurance testing in the GEP 6.5L(T) engine, frictional property analysis in standardized transmission compatibility tests, and the quantification of fuel consumption improvement through the use of lowered viscosity lubricants.

To begin, a preliminary group of desired chemical and physical properties were drafted and submitted to industry in a request for experimental products. These desired chemical and physical properties provided a framework for lubricant formulators for initial SCPL candidates. Five potential SCPL candidates were received for testing, and each was submitted for chemical and physical analysis to determine fit for purpose. Of the five candidates received, four were selected for further testing in high temperature engine applications, transmission frictional testing, and fuel consumption improvement quantification

For engine performance testing, the General Engine Products (GEP) 6.5L(T) engine, as used in the High Mobility Multipurpose Wheeled Vehicle (HMMWV), was used to complete high temperature oil endurance evaluations on each supplied candidate. In addition to the SCPL candidates, a three run repeatability matrix was completed using MIL-PRF-46167D, and testing of MIL-PRF-2014 (revisions G and H) and a commercial petroleum based API performance classification CJ-4 SAE 15W-40 diesel engine oil was also completed. This allowed for comparisons between current commercial products, current MIL specification products, and

supplied candidate performance. Table ES1 contains the end of test used oil analysis data for each test. All were run following an identical procedure, and testing was terminated at the completion of 210 hours or upon major oil degradation, whichever occurred first. From the chart, it can be seen that the baseline OEA-30 was a consistent 140 hour oil. This was an improvement over the MIL-PRF-2014G, but fell short of the most current revision, MIL-PRF-2104H. SCPL candidate performance varied between 84 and 168 hours, with two of the candidates showing strong performance overall.

Table ES1 – All Tests, End of Test Used Oil Analysis

		3-Run OEA-30			MIL SPEC & Commercial			SCPL Candidates			
Property	ASTM	Run-1	Run-2	Run-3	2104G	2104H	CJ-4	LO253071	LO254054	LO250033	LO251746
		140	140	140	84	154	210	126	84	168	168
Density	D4052	0.8834	0.891	0.888	0.9161	0.9276	0.920	0.896	0.899	0.8976	0.8859
Viscosity @ 100°C (cSt)	D445	10.78	11.56	11.06	17.58	25.47	25.59	12.17	12.71	15.11	11.96
Total Base Number (mg KOH/g)	D4739	2.46	2.08	2.55	0.74	1.17	0.82	2.61	2.77	3.37	3.84
Total Acid Number (mg KOH/g)	D664	8.62	10.33	9.97	12.87	17.1	11.06	10.86	12.59	11.25	9.19
Oxidation (Abs./cm)	E168 FTNG	102.69	137.87	119.59	171.63	217.99	117.53	136.69	174.4	133.86	99.08
Nitration (Abs./cm)	E168 FTNG	53.15	47.04	65.9	36.6	33.76	39.21	80.5	62.2	74.72	52.77
Soot	Soot	1.797	1.767	2.06	1.982	2.864	2.695	2.214	1.633	3.224	2.597
Wear Metals (ppm)	D5185										
Al		4	5	4	5	5	5.0	11	8	4	6
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		6	8	4	5	4	40.0	4	17	68	55
Ca		4711	4972	4709	3620	3056	3522.0	4629	4577	1286	1183
Cr		8	8	6	6	6	6.0	6	4	7	7
Cu		124	203	177	234	345	65.0	311	304	68	48
Fe		365	492	348	264	468	355.0	476	369	902	541
Pb		194	355	270	332	693	378.0	564	414	232	152
Mg		21	20	18	13	380	30.0	17	28	1717	1669
Mn		6	7	5	5	6	6.0	6	5	7	7
Mo		22	31	24	22	21	24.0	28	31	98	124
Ni		6	8	6	6	6	6.0	8	6	9	9
P		1362	1397	1314	1089	1302	1334.0	1366	1467	1484	1318
Si		20	24	36	51	38	46.0	56	54	63	53
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		5	7	7	8	<5	8.0	22	21	12	12
Sn		14	21	16	17	24	17.0	20	14	13	18
Zn		1854	1970	1821	1544	1914	1775.0	2306	2426	1940	1780
K		<5	<5	5	<5	<5	13.0	8	<5	5	<5
Sr		1	1	1	1	<1	1.0	2	2	<1	<1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		4	2	2	1	<1	<1	2	3	<1	<1

To determine transmission compatibility, several industry standardized transmission tests were completed on the SCPL candidates, including selected: Allison C4, Caterpillar TO-4, and John Deer Qualification tests. The SCPL candidates were found to have mixed results overall, and no candidates were able to pass all tests. Despite this, none of the oils tested showed signs of catastrophic incompatibilities, and are expected to be able to pass the various frictional evaluations with minor formulation changes. Table ES2 below summarizes the results from the various transmission tests.

Table ES2 – Transmission Compatibility Results

		LO250033 (INF 0W-30)		LO251746 (INF 0W-20)		LO253071 (LZ OEA-20)		LO254054 (LZ STOU)	
Description	**Method**	**Results**		**Results**		**Results**		**Results**	
FZG Scuffing	D5182-97	Pass (Fail Load Stage 12)*		Pass (Fail Load Stage 12)*		Pass (Fail Load Stage 12)*		Pass (Fail Load Stage 9)*	
FZG Wear	D4998	Pass*		Pass*		Pass*		Pass*	
		**Compared to CAT-TO-4 Fluid Specifications*				**Compared to CAT-TO-4 Fluid Specifications*			
C4 Seal Compatilibity		*Volume Change*	*Hardness*	*Volume Change*	*Hardness*	*Volume Change*	*Hardness*	*Volume Change*	*Hardness*
		Fail 1, Else Pass**	All Pass	Fail 1, Else Pass**	All Pass	Fail 1, Else Pass**	All Pass	Fail 1, Else Pass**	All Pass
		***Fail on elasomer N1 GR-N1386*							
		Slip Time	*Mid Point Friction Coef. MIN*	*Slip Time*	*Mid Point Friction Coef. MIN*	*Slip Time*	*Mid Point Friction Coef. MIN*	*Slip Time*	*Mid Point Friction Coef. MIN*
C4 Paper Friction		Pass	Pass	Pass	Pass	Pass	Fail	Pass	Pass
C4 Graphite Friction		Pass	Fail	Fail	Fail	Fail	Fail	Pass	Pass
JDQ-96 (1k cycles)			*Current Baseline*				*Current Baseline*		
			Relateive Capacity	*Torque Variation*			*Relateive Capacity*	*Torque Variation*	
			342,372	93,764			342,372	93,764	
		Relateive Capacity	*Torque Variation*	*Relateive Capacity*	*Torque Variation*	*Relateive Capacity*	*Torque Variation*	*Relateive Capacity*	*Torque Variation*
		403,778	255,990	398,534	253,990	360,738	164,190	386,450	192,440
CAT TO-4		**LO253071 (LZ OEA-20)**		**LO254054 (LZ STOU)**		**LO250033 (INF 0W-30)**		**LO251746 (INF 0W-20)**	
Sequence 1220									
Dynamic Coef vs Cycle		Pass		Fail		Pass		Fail	
Dynamic Coef vs Load		Pass		Fail		Pass		Fail	
Dynamic Coef vs Speed		Pass		Fail		Pass		Fail	
Energy Limit		Pass		Pass		Pass		Pass	
Static Coef vs Load		Pass		Pass		Pass		Fail	
Static Coef vs Speed		Pass		Pass		Pass		Fail	
Energy Limit		Pass		Pass		Pass		Pass	
Total Wear		0.039		0.08		0.014		0.039	
Sequence 1222									
Dynamic Coef vs Cycle		Fail		Pass		Fail		Fail	
Dynamic Coef vs Load		Fail		Pass		Fail		Fail	
Dynamic Coef vs Speed		Fail		Pass		Pass		Fail	
Energy Limit		Pass		Pass		Pass		Pass	
Static Coef vs Load		Fail		Fail		Pass		Fail	
Static Coef vs Speed		Pass		Fail		Pass		Fail	
Energy Limit		Pass		Pass		Pass		Pass	
Total Wear		0.03		0.039		0.028		0.007	
Friction Retention									
		Pass		Pass		Pass		Pass	

Lastly, fuel consumption improvement evaluations were completed to quantify improvement with the use of low viscosity lubricants over traditional higher viscosity diesel engine oils. The GEP 6.5L(T) engine was again used for testing due to its utilization of a fully mechanical fuel injection system which added greater consistency to fuel consumption measurements. A 14 mode test cycle was developed from data acquired from HMMWV field operations taken at Ft. Hood, Texas, and reference runs were completed using a straight SAE 40 grade engine oil. Once acceptable consistency was achieved in the test, a full matrix of oils were run to determine percent fuel consumption improvement. Candidate SCPL oils showed between 1.5 to 2.5% fuel consumption improvement over the straight SAE 40 grade baseline, which translates anywhere between 0.5 to 1.5% improvement over standard military diesel engine oils.

From positive results seen during the engine, transmission, and fuel consumption testing, two candidates, LO253071 and LO251746, should be resubmitted to their respective supplier for further revisions. LO253071 was chosen primarily due to its close ties to the currently approved MIL-PRF-46167D arctic engine oil, despite its less than desirable performance during engine testing. LO251746 was chosen because of its excellent performance as seen during the 6.5L(T) high temperature endurance testing. Both candidates had some shortcomings in the transmission testing section, but appear to require only minor formulation changes to meet desired performance levels in each area of interest. Main areas of emphasis for reformulation efforts for both candidates should be focused on:

- Improved oxidation stability
- Improved frictional response in standardized transmission testing

As one of the primary goals of the SCPL, improved oxidation stability and overall oil degradation control in severe applications will ultimately lead to extended drain benefits and increased engine protection. These two aspects are key to the implementation of the SCPL. In addition, changes to each formulation to improve frictional response in transmission applications will be required so that the SCPL can serve as a drop in replacement for the currently utilized MIL-PRF-2104H products.

FOREWORD/ACKNOWLEDGMENTS

The U.S. Army TARDEC Fuel and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, performed this work during the period March 2009 through January 2012 under Contract No. W56HZV-09-C-0100. The U.S. Army Tank-Automotive RD&E Center, Force Projection Technologies, Warren, Michigan administered the project. Mr. Allen Comfort served as the TARDEC contracting officer's technical representative.

The authors would like to acknowledge the contribution of the TFLRF technical support staff along with the administrative and report-processing support provided by Dianna Barrera.

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ACRONYMS AND ABBREVIATIONS

API	American Petroleum Institute
ASTM	American Society of Testing Materials
ATF	Automatic Transmission Fluid
bhp	brake horse power
bsfc	brake specific fuel consumption
CAT	Caterpillar
CL	Chemistry Lab
coeff	coefficient
COTR	Contracting Officer Technical Representative
cP	centipoise
CRC	Coordinating Research Council
cSt	centistokes
EOT	End of Test
FRRET	Friction Retention
ft	feet/foot
FZG	Forschungsstelle fur Zahnrader und Getriebebau (Technical Institute for the Study of Gears and Drive Mechanisms)
GEP	General Engine Products
HDO	Heavy Duty Oil
HMMWV	High Mobility Multipurpose Wheeled Vehicle
hp	horse power
JDQ	John Deere Qualification
JP-8	Jet Propulsion-8
KOH/g	potassium hydroxide per gram
lb	pound
LO	Lab Oil
max	maximum
MIL	Military
min	minimum
N	Newton
NVH	Noise, Vibration, and Harshness
OE	Oil Engine
OEA	Oil Engine Arctic
OEM	Original Equipment Manufacturer
ppm	parts per million
psi	pounds per square inch
psiA	pounds per square inch absolute
RPM	Revolutions Per Minute
SAE	Society of Automotive Engineers
SCPL	Single Common Powertrain Lubricant
SwRI	Southwest Research Institute
TAN	Total Acid Number
TARDEC	Tank Automotive Research and Development Engineering Center
TBN	Total Base Number
TFLRF	TARDEC Fuels and Lubricants Research Facility

1.0 INTRODUCTION & BACKGROUND

The U.S. Army has a desire to consolidate multiple lubricant specifications into a single specification, or Single Common Powertrain Lubricant (SCPL). The application of this fluid would include engine lubrication, power shift transmission operation, and limited use in hydraulic systems where MIL-PRF-2104 is currently used. The SCPL must be designed to operate in ambients ranging from low temperature arctic, to high temperature desert type conditions, representative of the wide range of potential military operating condition. In addition, the SCPL must meet or exceed performance currently attained by approved MIL specification products. By achieving these goals, multiple specifications could be reduced into a single specification, or SCPL, that could be used successfully in all tactical and combat vehicles, despite their seasonal or geographical location. The development of this fluid has the potential to reduce the logistical burden on the military's supply chain, by requiring that only one lubricant would need to be procured and distributed throughout its worldwide operations.

Due to the extreme application requirements and performance goals, it was desirable that the SCPL be formulated from synthetic basestocks. These synthetic basestocks typically have a higher cost when compared to traditional petroleum derived basestocks. To offset the increased price, several performance goals must be met such as increased fuel efficiency and extended drain intervals. Due to the cold climate performance requirements of the SCPL, lower viscosities must be obtained than those typically found in commercial heavy duty diesel engine oils. Current research has shown that there is a potential reduction in fuel consumption through the use of low viscosity lubricating fluids [1,2]. This change in fuel consumption is attributed to the reduction in mechanical losses within the system. These mechanical losses can be related to frictional properties, pumping efficiencies, and overall bulk churning. Although reductions in fuel consumption due to viscosity changes are expected to be relatively small (1-2%), when multiplied over a large group of vehicles such as the military's combat and tactical fleet, the fuel savings can be substantial and help to offset the costs associated with the use of synthetic basestocks. Another advantage of these premium basestocks is a typically increased resistance to oil degradation which allows the extension of time required between drain intervals. This is another factor that can positively impact the overall SCPL cost effectiveness.

This report will focus on the preliminary development of the SCPL from testing completed at the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI) in San Antonio, Texas. Primary performance investigations of candidates supplied for SCPL testing included: chemical and physical analysis to determine fit for purpose, high temperature endurance testing in the GEP 6.5L(T) engine, frictional property analysis in standardized transmission compatibility tests, and the quantification of fuel consumption improvement from lowered viscosities.

2.0 OBJECTIVE & APPROACH

The overall objective of this program was to evaluate industry provided SCPL candidates to determine their performance when used in military applications. This data would reinforce the previously completed feasibility efforts [3,4,5], and provide a baseline data set to begin the iterative process of developing the SCPL.

2.1 DEFINING THE SCPL

To begin the SCPL development process, a preliminary group of desired chemical and physical properties were drafted by TFLRF staff and the contracting technical representative (COTR) at the U.S. Army Tank Automotive Research & Development Engineering Center (TARDEC). These desired chemical and physical properties provided a framework for initial SCPL candidates. These parameters and target properties can be seen below in Table 1.

Table 1 – Chemical & Physical Property Targets for SCPL

Property	Minimum Acceptable	Target
Kinematic Viscosity @-40°C, cSt, max	16,000	12,000
Kinematic Viscosity @-48°C, cSt, max	55,000	45,000
Pour Pt, °C, min	-55	-60
Low Temperature Cranking @-35°, cSt, max	4,700	4,400
Low Temperature Pumping @-40°C, cSt, max	14,000	12,000
Brookfield Viscosity @-40°C, cP, max	13,000	10,000
NOACK Volatility, %, max	11	10
Shear Loss, CEC-L45-T-93 (KRL), %, max	8	6

From these targets, a request for experimental products was released to various commercial lubricant and additive companies to solicit potential candidates for testing. A total of five candidate lubricants were received to be evaluated as a potential SCPL from these efforts.

2.2 ENGINE DURABILITY TESTING

Due to the low temperature properties required to meet SCPL guidelines, candidate SCPLs were expected to be formulated to attain lower viscometric properties than those seen in traditional heavy duty diesel engine oils. To ensure that these low viscosity lubricants provided adequate engine component protection at all conditions, particularly desert operations, high temperature engine oil endurance testing was completed to assess candidate performance at worst case conditions. The General Engine Products (GEP) 6.5L(T) diesel engine, as used in the High Mobility Multipurpose Wheeled Vehicles (HMMWV), was selected as the test bed for determining engine durability using the SCPL. The GEP 6.5L(T) engine is a 6.5L V8, turbocharged, non-intercooled, indirect injected, roller follower, cam in block engine. Engine fueling is controlled by a mechanical Stanadyne DB2-5079 rotary injection pump in a pump-line-nozzle configuration. The GEP 6.5L(T) engine was selected primarily because of its traditionally rapid degradation of engine oil during use (i.e. high severity), and the engine family's high density in the current military fleet (engine family includes the GEP 6.2L(NA), 6.5L(NA), and 6.5L(T) in all variants of the HMMWV).

To accurately predict the SCPL performance and establish confidence in SCPL test results, several key tasks were identified and incorporated into the test plan. From the previously completed feasibility study [3,4], the current MIL-PRF-46167D OEA-30 arctic engine oil was tested as the de facto SCPL, and was again used during this program as a baseline to compare the newly received SCPL candidates. In an effort to gain confidence in the results from a single engine endurance run of each SCPL candidate, it was desirable to establish/identify the overall repeatability of the endurance test with the selected baseline lubricant. It was decided that a total of three (3) repeatability runs would be completed using the OEA-30 engine oil to determine variance in engine oil degradation throughout the test cycle, evaluate any variation in critical controlled parameters during testing, and identify any major discrepancies in post test metrology and ratings. Additional single "baseline" tests were completed using MIL-PRF-2104 OE/HDO

(G and H revisions), as well as a commercial off the shelf petroleum based API performance classification CJ-4 SAE 15W-40 diesel engine oil. These tests were to be used as a comparison of candidate SCPL performance to current military oils and that which is available from the industry. All testing (SCPL, MIL Specification, and commercial) was completed to determine performance of the engine oil in question with respect to engine wear, oil life expectancy, and deposit formation.

2.3 TRANSMISSION COMPATIBILITY

In addition to being utilized in the engine crankcase, the SCPL was intended to be used in power shift transmission applications where MIL-PRF-2104 products are currently being used. During the feasibility study of the SCPL [5], multiple grades of engine oils were tested in industry standardized transmission tests to understand the engine oils impact on transmission performance. To ensure SCPL candidate compatibility in these applications, several of the same industry established standardized transmission tests were again completed to assess each SCPL candidates' frictional properties, as well as additional testing to determine loaded gear protection capabilities. These tests included:

- Caterpillar TO-4
    - Sequence 1220 – Sintered Bronze
    - Sequence 1222 – Wheel Brake Paper
    - Friction Retention (FRRET) – Sintered Bronze
    - FZG Scuffing (ASTM D5182)
    - FZG Wear (ASTM D4998)
- Allison C4
    - High Energy Friction – Graphite
    - High Energy Friction – Paper
    - Elastomer/Seal Compatibility
- John Deere Qualification
    - JDQ-96 Wet Brake (abbreviated 1k cycles)

From these standardized tests, SCPL results could be compared to results from automatic transmission fluid (ATF) reference tests, and results achieved by current MIL-PRF-2104 products. It was expected that with the utilization of formulations based off of engine oils in these applications, some of the benefits of a purpose built ATF could potentially be lost. The goal for the SCPL in these tests was to ensure that adequate performance was retained (i.e. acceptable friction properties, torque capacity, wear protection, etc), and that the SCPL candidates would meet or exceed the performance of MIL-PRF-2104 oils currently being used. Although operator feel and noise, vibration, and harshness (NVH) effects are important in the commercial formulation of an ATF, the primary concern for the SCPL development was on overall functionality and durability of the equipment.

2.4 ENGINE FUEL CONSUMPTION IMPROVEMENT

Evaluation of the candidate lubricants for fuel consumption effects was also conducted using the GEP 6.5L(T) diesel engine. While other engines were investigated during the development phase, the mechanical fueling control offered by the 6.5L(T) engine was critical for test repeatability. The cycle used to measure fuel consumption changes evaluated each lubricant over a range of load points and oil sump temperatures derived from previously acquired data via HMMWV operation at Ft. Hood, TX. In addition to fuel consumption improvement quantification using fresh oil, several used oil drains from the SCPL endurance tests were also run to determine the lubricants end-of-life fuel consumption benefits. Additional information regarding the development of the fuel economy test procedure can be found in Appendix H.

3.0 DISCUSSION OF RESULTS

The following sections outline and discuss test results acquired during the development phase of the SCPL. These included: chemical and physical analysis, engine oil durability testing, transmission compatibility analysis, and fuel consumption improvement quantification.

3.1 SCPL CANDIDATE CHEMICAL & PHYSICAL PROPERTIES

As previously discussed, each SCPL candidate received for consideration was initially tested to document its chemical and physical properties in an effort to determine how closely it met the goals outlined in the request for experimental products. Preliminary testing results from the SCPL candidates can be seen in Table 2. From this analysis, candidate CL10-00249 was not found to meet the desired low temperature viscosity targets, specifically viscosity at -48°C and the low temperature pour point. Due to this, it was excluded from further testing. The remaining candidates were generally found to meet all of the targets with the exception of NOACK volatility. In addition, one of the candidates LO25033, was also outside of the minimum acceptable range for Brookfield viscosity. Despite this, the suppliers of the candidates in question expressed great interest and support in the SCPL program, so it was decided that these four lubricants would be tested as potential SCPL candidates. Industry support would prove vital in the future, as each supplier would be asked to improve their products based on the preliminary SCPL development testing.

Table 2 – Baseline & SCPL Candidate Preliminary Chemical & Physical Properties

				MIL-PRF-46167D OEA-30	Industry Supplied SCPL Candidate Lubricants				
Method	**Temp**	**Property**	**Units**	**LO241026**	**LO253071**	**LO254054**	**CL10-00249**	**LO250033**	**LO251746**
ASTM D445	**-40°C**	**Viscosity**	cSt	10054.2	7661.6	4884.54	7244.5	12030.41	11158
ASTM D445	**100°C**	**High Temp Viscosity**	cSt	10.2	8.42	7.33	9.51	10.01	8.13
ASTM D445 LT	**-48°C**	**Low Temp Viscosity**	cSt	52548.1	36325.09	21055.6	**	51937.17	38427.23
ASTM D2983	**-40°C**	**Brookfield Viscosity**	cPs	14497	10878	6669	9668	13877	11158
ASTM D4683 TBS	**150°C**	**Tapered Bearing Shear Viscosity**	cPs	3	2.69	2.5	3.32	2.97	2.59
ASTM D4684	**-40°C**	**Apparent Viscosity**	mPa/s	13400	10300	6600	9600	12900	10000
ASTM D5293 COLD	**-35°C**	**Cold Cranking**	mPa/s	4200	4190	3050	4550	4090	4070
ASTM D5800		**Noack Volitility**	wt%	10.7	10	12	10.6	11.9	12.4
ASTMD7109	**100°C**	**Shear Stability**							
		Viscosity @ 100C after 30 Passes	cSt	8.9	8.33	7.32	9.51	9.97	8.11
		Viscosity loss after 30 Passes	% Loss	12.8	1.07	0.14	0	0.4	0.25
		Viscosity @ 100C after 90 Passes	cSt	8.7	8.22	7.36	9.48	9.94	8.07
		Viscosity loss after 90 Passes	% Loss	14.4	2.38	0.41	0.32	0.7	0.74
ASTM D97		**Pour Point**	°C	-60	-60	<-63	-51	-57	<-60
**The sample is too viscous to obtain repeatable results.									

3.2 ENGINE DURABILITY TESTING

The following section discusses the results attained during the engine durability portion of the SCPL development. Focus areas included construction of the engine durability test stand, description of the engine durability test cycle, completion of the repeatability baseline runs, and the SCPL candidate evaluations.

3.2.1 Test Stand Construction

A GEP 6.5L(T) high temperature engine oil endurance test stand was constructed to evaluate all lubricants for the SCPL program. As previously discussed, the GEP 6.5L(T) diesel engine was selected for SCPL evaluations due to its high severity levels on engine lubricants, and its high density in the military's tactical fleet (all HMMWV variants). The GEP 6.5L(T) engine utilized for testing was purchased directly from General Engine Products, a subsidiary of AM General, the original equipment manufacturer (OEM) for the HMMWV. The GEP 6.5L(T) engine model tested is rated at 190 hp at 3400 rpm, and 380 lbft at 1800 rpm using diesel fuel. When utilizing JP-8, as was the case during the SCPL testing, power levels typically drop to around 170 hp and 320 lbft of torque at their respective peaks. To serve as a consistent test bed, this dedicated engine test stand was built to complete all of the high temperature evaluations for each SCPL candidate tests. A picture of the GEP 6.5L(T) engine installation can be seen below in Figure 1.

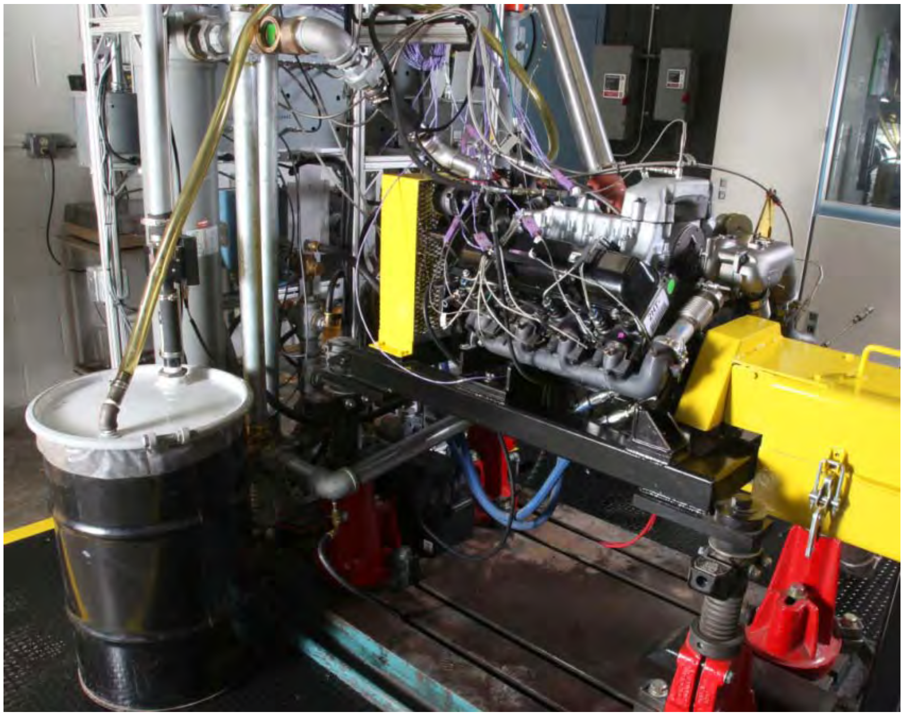


Figure 1 – General Engine Products 6.5L(T) Test Cell Installation

The 6.5L(T) engine was mounted in an engine dynamometer test cell for SCPL testing and equipped with all necessary ancillary equipment to operate the engine with the exception of accessory equipment that would be installed and utilized in a vehicle (i.e. alternator, cooling fan, etc). The bulleted list below outlines the basic hardware constructed and utilized in the SCPL engine oil test program:

- The engine used SwRI developed PRISM data acquisition software to monitor and control engine operation throughout testing. Monitored engine parameters included all critical temperatures, pressures, and flow rates, as well as engine speed and output power/torque.
- Engine loading was provided by an eddy current engine dynamometer and an electro mechanical throttle actuation system. The dynamometer controlled engine speed, while the throttle actuation system adjusted the injection pumps rack position via a throttle cable.
- Liquid-liquid heat exchangers were used to regulate the engine water jacket and oil sump temperatures with building supplied process water.

- Fuel was supplied from bulk storage tanks to an engine "day-tank" that served as a common location for the engine supply and return lines. The engine's fuel consumption was monitored by a coriolis flow meter for measuring the make-up fuel required to maintain the day tank at a constant volume.
- Inlet fuel temperature was controlled by a heater control loop to maintain steady inlet fuel temperature throughout testing. The control loop maintained a reservoir of glycol-water coolant at a specified temperature, and was then used to heat the incoming fuel to the desired set point through a liquid-liquid heat exchanger.
- Engine inlet air was drawn past a chilled water core to lower intake air temperatures prior to the engine air filtering system. This was required to maintain exhaust gas temperatures at safe levels during the long segments of continuous operation at rated speed and load during the test cycle. Air was filtered through an OEM-style air filter housing with an adjusting valve to vary intake air restriction prior to the turbocharger inlet.
- Engine exhaust gases were ducted into an exhaust ventilation system integrated into the engine laboratory building. Back-pressure was controlled via a butterfly valve located in the exhaust stack between the engine and the buildings common exhaust header before exiting the test cell.
- Engine blow-by gases were ducted into a drum to capture any entrained oil. The drum was vented through a hot-wire flow meter to monitor engine blow-by rates, and then ducted to the buildings exhaust ventilation system at ambient pressure (to not effect crankcase pressure) to expel blow-by gasses from the test cell.
- Engine coolant was a 60/40 blend of ethylene glycol and de-ionized water.
- Fuel used during testing was JP8 blended at location from commercially available Jet-A with a double max-treat rate of lubricity enhancer DCI-4A. (Appendix I)

3.2.2 Test Cycle Operation

The test cycle used for lubricant evaluations was a modified version of the 210 hour Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test [6]. Modifications were made to the test temperature specifications to increase the severity on the oil being tested. Test termination would occur at the

completion of the scheduled 210 hours or upon major oil degradation, which ever occurred first. The test cycle consisted of alternating between two hours at rated speed and load followed by one hour at no-load idle speed. This was completed for 14 hours daily, followed by a 10 hour engine-off soak period to allow time for oil degrading chemical reactions to take place in the oil sump. Engine oil temperatures were elevated during rated speed and load test conditions to simulate high ambient temperatures typical of desert operations. During no-load idle steps, engine temperatures (oil sump and coolant) were lowered to further stress the lubricant through thermal cycling. Critical engine operating parameters controlled throughout testing are specified below in Table 3. Engine output torque was controlled for each test to a value of 256 lbft of torque. This value, which is a slight reduction of the typical total capable torque output of the GEP 6.5L(T), was selected so that any full load output variation between test engines would not bias SCPL evaluations. To target this output torque, the throttle actuation control system would slightly back off of the injection pump rack position to meet the specified output, and control it over the test duration. This provided a consistent loading of all the internal engine components, so that each lubricant tested would be subject to the same engine conditions. The oil sump temperature specification of 260°F for the rated step was selected based off a 4% increase in general requirement for MIL-PRF-2104 lubricants to be capable of operating at 250°F continuously. This placed further demand on the SCPL candidates to be able to control engine oil oxidation which is a function of time and temperature. Coolant jacket outlet temperature was maintained at 205°F during rated steps to maintain engine integrity throughout the test cycle.

Table 3 – Tactical Wheeled Vehicle Test Cycle Operating Conditions

Parameter	Rated Speed & Load	No-Load Idle
Engine Speed [RPM]	3400 +/- 25	900 +/- 25
Engine Output Torque [lb*ft]	256 +/- 5	Not specified
Water Jacket Out [°F]	205 +/- 5	100 +/- 5
Oil Sump [°F]	260 +/- 5	125 +/- 5

Used engine oil samples were collected every 14 hours for analysis. This was used to assess the condition of the lubricant and to determine test termination if necessary. Tests conducted on daily samples are outlined below in Table 4. Engine oil level was replenished daily to restore it to its proper level. All engine oil additions and samples were weighed throughout testing to track engine oil consumption.

Table 4 – Used Oil Analysis Tests

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

3.2.3 Engine Metrology and Ratings

Each SCPL evaluation started with a new GEP 6.5L(T) engine. Considerations were made to rebuild and reuse test engines as their condition allowed, but concerns over test biasing due to some engines being previously run-in were raised. Due to this, new engines were used for each test to increase consistency and ensure that each candidate utilized an engine of the same condition.

Prior to testing, each engine was disassembled to complete a pre-test inspection and metrology process. Engines were inspected for manufacturing defects (corrected as needed), and measurements of critical engine components were taken to document pre-test engine condition. These pre-test metrology procedures included measurements of:

- Crankshaft main bearing mass
- Connecting rod bearing mass

- Top, second, and bottom piston ring mass
- Top, and second piston ring radial thickness
- Piston ring end gap (in block)
- Piston skirt diameter
- Piston bore diameter (measured top, mid, and bottom of bore in the transverse and longitudinal directions)

After the inspection and metrology process was completed, engines were reassembled according to factory specifications. During assembly, parts requiring lubrication were assembled using EF-411 assembly lubricant. This assembly lubricant is used in many ASTM standardized tests procedures, and has no additives in order to remove any bias on subsequent lubricant test data.

At the completion of each endurance test, the engine was once again disassembled and inspected. This allowed for documentation of wear experienced over the test duration. Since each test was terminated based on used oil condition and not operated for a fixed period of time, straight across comparisons of engine wear for each lubricant from metrology measurements cannot be completed. Many wear parameters are a function of total engine operation time, with the lubricant condition having a smaller impact. Thus, wear experienced in an 84 hour test cannot be directly compared to a 140 hour test. Regardless, metrology measurements still prove useful in showing indications of overall wear patterns, and help to identify any large outliers during testing. Similar to pretest metrology, post-test procedures included measurements of:

- Crankshaft main bearing mass
- Connecting rod bearing mass
- Top, second, and bottom piston ring mass
- Top, and second piston ring radial thickness
- Piston ring end gap (in block)
- Piston skirt diameter
- Piston bore diameter (measured top, mid, and bottom bore in the transverse and longitudinal direction)

In addition to post-test metrology, engine pistons received deposit ratings to quantify the amount and location of carbonaceous and lacquer type deposits present on the piston. This process was completed following industry standardized CRC piston deposit ratings procedures. This was done to quantify the overall cleanliness of the lubricant and its ability to control harmful engine deposits when used in severe conditions.

3.2.4 Repeatability Testing

As previously stated, three repeatability runs were completed using the MIL-PRF-46167D OEA-30 arctic engine oil over the GEP 6.5L(T) high temperature oil endurance test cycle. This was completed to help evaluate any variation in critical controlled parameters during testing, and identify any major discrepancies in used oil analysis and post test metrology and ratings. Each of the three baseline OEA-30 tests were completed following the test cycle previously discussed, and each test was terminated at 140 hours of testing due to engine oil degradation. Table 5 shows the engine operating summary for each repeatability run during the rated speed and load step. This data is derived from an average value of each critical test point over the entire time spent at rated conditions. This shows the consistency of engine control between each test that was achieved. The most critical test points include the engine output torque, coolant outlet temperature, oil sump temperature, and fuel inlet temperature. Each of these parameters were successfully controlled for the three repeatability runs, which can be seen in the average and standard deviation data.

Table 5 – Repeatability Runs, Engine Operating Summary

		Repeatability Run - 1 Rated Conditions (3400 RPM)		Repeatability Run - 2 Rated Conditions (3400 RPM)		Repeatability Run - 3 Rated Conditions (3400 RPM)		3-Run Average Rated Conditions (3400 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.01	0.79	3400.02	0.75	3400.03	0.73	3400.02	0.76
Torque*	lb*ft	255.49	3.39	256.41	4.72	256.27	1.75	256.06	3.29
Fuel Flow	lb/hr	77.76	9.18	81.53	2.92	77.54	2.19	78.94	4.76
Power*	bhp	165.40	2.19	165.99	3.05	165.90	1.12	165.76	2.12
BSFC*	lb/bhp*hr	0.470	0.056	0.491	0.018	0.467	0.013	0.476	0.029
Temperatures:									
Coolant In	°F	191.68	2.58	191.52	0.99	192.03	0.82	191.74	1.46
Coolant Out	°F	204.86	2.45	205.04	0.85	205.00	0.68	204.97	1.33
Oil Sump	°F	260.01	0.62	259.90	1.79	260.00	0.37	259.97	0.93
Fuel In	°F	95.07	1.84	95.34	0.93	95.02	0.35	95.14	1.04
Intake Air	°F	91.05	7.01	82.03	5.99	71.09	2.66	81.39	5.22
Cylinder 1 Exhaust	°F	1102.53	13.18	1077.39	19.14	1114.09	16.49	1098.00	16.27
Cylinder 2 Exhaust	°F	1085.62	17.85	1197.34	18.56	1073.72	18.11	1118.89	18.17
Cylinder 3 Exhaust	°F	1188.99	15.62	1217.78	18.61	1204.50	12.75	1203.76	15.66
Cylinder 4 Exhaust	°F	1094.77	12.55	1177.12	20.40	1083.83	16.72	1118.57	16.56
Cylinder 5 Exhaust	°F	1145.91	14.06	1184.86	25.62	1160.56	17.00	1163.78	18.89
Cylinder 6 Exhaust	°F	1127.73	15.35	1154.17	31.81	1136.11	17.24	1139.34	21.47
Cylinder 7 Exhaust	°F	1092.92	18.03	1192.20	26.65	1094.47	13.12	1126.53	19.27
Cylinder 8 Exhaust	°F	1172.12	16.07	1212.57	20.18	1135.14	16.43	1173.28	17.56
Pressures:									
Oil Galley	psi	39.93	0.53	36.43	0.68	39.28	0.53	38.55	0.58
Ambient Pressure	psiA	14.21	0.07	14.16	0.10	14.19	0.05	14.19	0.07
Boost Pressure	psi	4.54	0.09	5.06	0.11	4.28	0.06	4.63	0.09

* Non-corrected Values

Each of the three repeatability runs were terminated at 140 hours after experiencing major oil degradation. Further operation of the engine would have resulted in significant main and connecting rod bearing damage due to the oil's condition at test termination. If continued, the oil would have experienced exponential increases in the oxidization levels, wear metal accumulation, and total acid number (TAN) accumulation. Figure 2 shows the TAN and total base number (TBN) response for each of the three runs. Each run experienced similar degradation rates in the TBN over the first 84 hours, and TAN/TBN cross between the 84 and 98 hour samples. Two generally accepted indicators for oil change are when a TAN/TBN cross over occurs, or when TBN drops below 4 mg KOH/g. Both of these criterion would be met by the 98 hour point in each repeatability test.

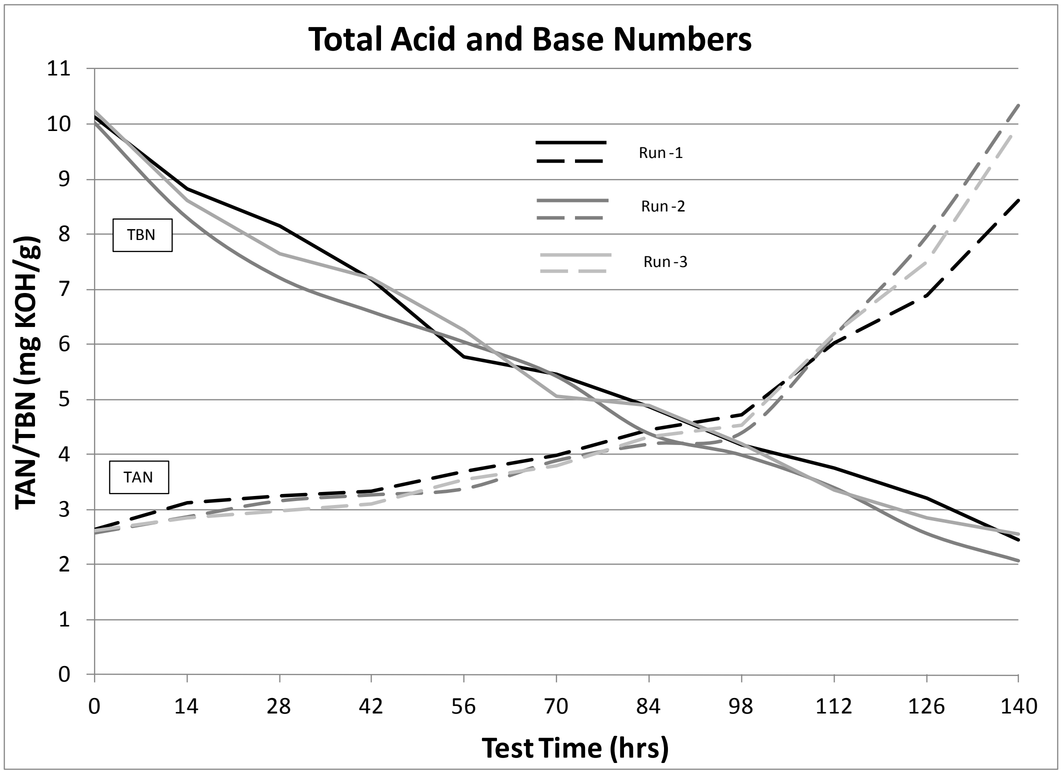


Figure 2 – Repeatability Runs, TAN/TBN Response

To stress the oil as far as possible, testing was continued until other used oil properties, primarily wear metal accumulation, began to rapidly change signifying the imminent break down of the oil. Figure 3 shows the accumulation of lead and copper wear metals in the engines oil. Lead is a primary indicator of the GEP 6.5L(T) engine’s main and connecting rod bearing distress. The engine’s bearings are constructed of a copper-lead overlay, therefore large changes in lead accumulations are generally followed by increases in copper accumulation. Early in the test, steady small changes in lead and copper concentration are normal. Typical increases every 14 hours are generally in the 2-5 ppm range for lead, and 1-2 ppm for copper. Once the TAN/TBN cross over occurs and TBN continues to deplete, the oils ability to neutralize harmful acid formations is limited, and engine bearings begin to be damaged. Indicators of imminent oil failure in the 6.5L(T) engine usually include a sharp increase in the lead accumulation, typically doubling or tripling in concentration, followed by a rapid accumulation in copper. Test termination was generally determined at this time, or no later than one test day (14 test hours) after this phenomenon was noted.

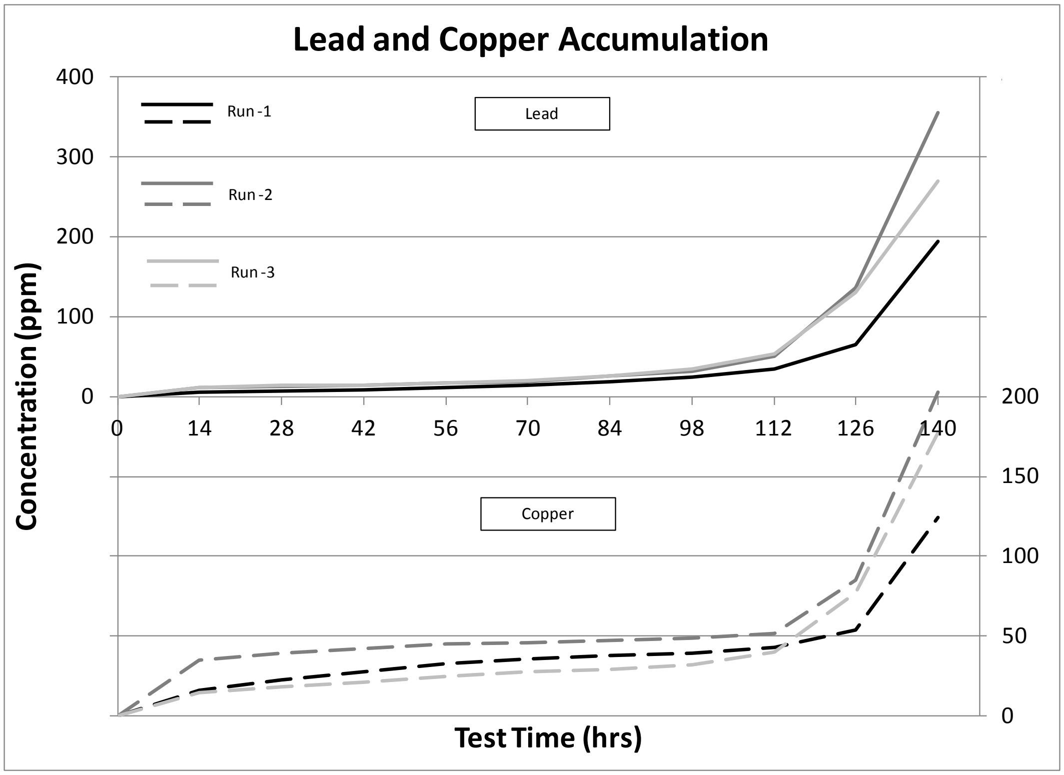


Figure 3 – Repeatability Runs, Lead & Copper Accumulation

In addition to wear metal changes, the rate of oxidation increase also changes exponentially preceding oil failure. Figure 4 shows the oxidation and nitration response for each test. Note the constancy in the first 98 hours of testing between each run.

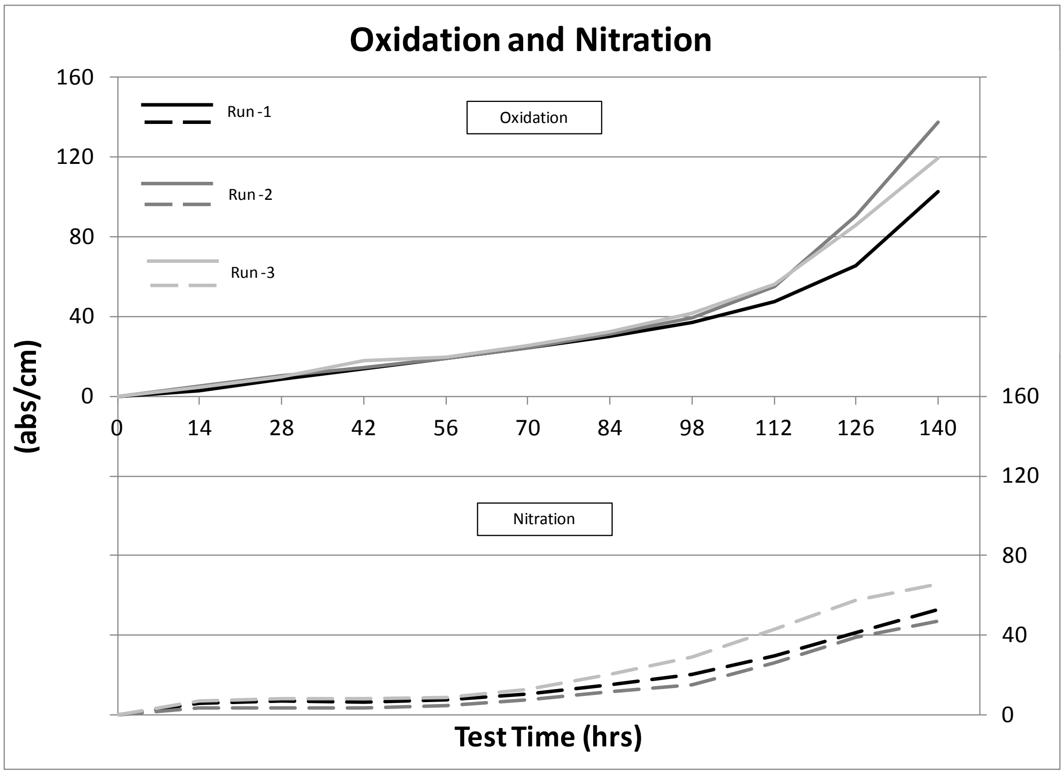


Figure 4 – Repeatability Runs, Oxidation and Nitration Response

Soot accumulation during testing, although not excessive, was also uniform across each of the tests. This acts as another indicator that a high level of consistency was achieved between each test, and that results from a subsequent single SCPL run would be expected to also repeat if tested multiple times. Figure 5 shows the total soot accumulation across each run for the OEA-30.

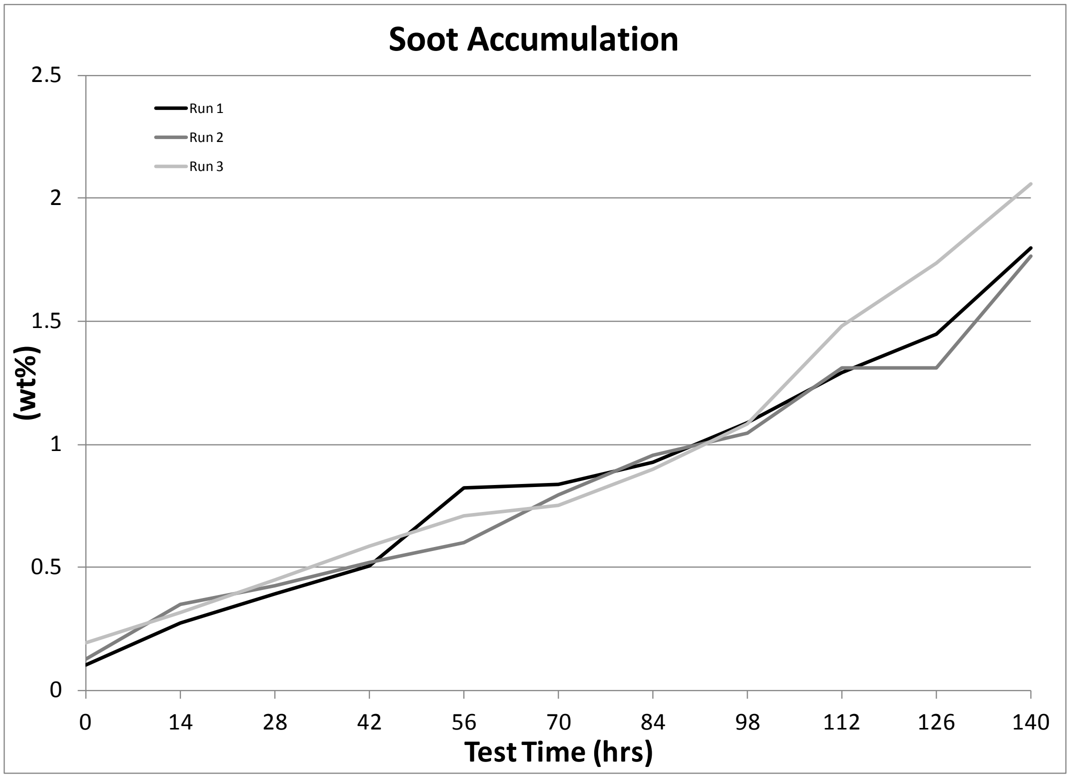


Figure 5 – Repeatability Runs, Soot Accumulation

Table 6 shows the accumulated oil consumption rate for each test. This is calculated from the difference of the total engine oil additions (test fill and daily top off) and total engine oil subtractions (daily samples) divided by the total number of test hours. Inconsistent oil additions can have a large impact on daily used oil analysis, and can potentially bias results. From this data, we can see that the overall 3-run average oil consumption rate was 0.076 lbs/hr.

Table 6 – Repeatability Runs, Accumulated Oil Consumption Rate

	Repeatability Run - 1	Repeatability Run - 2	Repeatability Run - 3	3-Run Average
Engine Oil Consumption [lb/hr]	**0.061**	**0.082**	**0.086**	**0.076**

From the overall consistency seen in acquired data to this point, bench marks for typical metrology and ratings data were established. Normal ranges for main and connecting rod bearing wear were identified, and can be seen in Table 7 and Table 8 respectively. Main bearing average and maximum measurements are shown without the incorporation of the number 3 thrust bearing. This was due to variations in engine thrust loading dependant on interactions between the dynamometer and engine coupling. From past experience, varying thrust loads applied during testing have resulted in inconsistent thrust surface wear which biases main bearing mass change measurements. From the remaining selected measurements, typical main bearing mass change averages were seen to vary between 0.03 and 0.06 grams across each of the three tests. Average and maximum values shown are referenced to each individual run, and are calculated from the average mass change of main bearings 1, 2, 4, and 5.

Table 7 – Repeatability Runs, Main Bearing Mass Change

Main Bearing Mass Changes (grams)				
Main Bearing	**Shell**	**Run 1**	**Run 2**	**Run 3**
1	Top	0.0266	0.0346	0.0220
	Bottom	0.0639	0.0752	0.0152
2	Top	0.0171	0.0204	0.0154
	Bottom	0.0831	0.1285	0.0322
3	Thrust Bearing Excluded From Calculations			
4	Top	0.0143	0.0178	0.0150
	Bottom	0.0702	0.0508	0.0267
5	Top	0.0427	0.0637	0.0804
	Bottom	0.1192	0.1111	0.0678
	Maximum	0.1192	0.1285	0.0804
	Average	0.0546	0.0628	0.0343

Similar to the main bearings, connecting rod main bearing mass variations can be seen to range between 0.03 to 0.04 grams across each of the three repeatability runs. Average and maximum values shown are referenced to each individual run, and are calculated from the average mass change of the top and bottom shells for all cylinders.

Table 8 – Repeatability Runs, Connecting Rod Bearing Mass Change

Rod Bearing Mass Changes (grams)				
Rod Bearing	Shell	Run 1	Run 2	Run 3
1	Top	0.0263	0.0148	0.0276
	Bottom	0.0616	0.0150	0.0621
2	Top	0.0206	0.0165	0.0123
	Bottom	0.0304	0.0087	0.0363
3	Top	0.0178	0.0235	0.0178
	Bottom	0.0279	0.0227	0.0390
4	Top	0.0271	0.0242	0.0133
	Bottom	0.1010	0.0190	0.0225
5	Top	0.0339	0.0188	0.0175
	Bottom	0.0884	0.0187	0.0359
6	Top	0.0190	0.0173	0.0000
	Bottom	0.0371	0.0259	0.0000
7	Top	0.0513	0.1371	0.0333
	Bottom	0.0694	0.0579	0.0332
8	Top	0.0253	0.0198	0.0163
	Bottom	0.0538	0.0130	0.0641

Maximum	0.1010	0.1371	0.0641
Average	0.0432	0.0283	0.0270

Each camshaft removed received precision measurements across lobe peaks to establish norms in surface variation and provide an indication of the lubricants ability to protect the cam and roller lifter interface. Lobe peak variation values for each of the three runs can be seen below in Table 9. Values shown are an average of all sixteen lobes for each individual run.

Table 9 – Repeatability Runs, Camshaft Lobe Peak Variation

Cam Lobe Waviness Parameter (µm)			
Cam Lobe	Run 1	Run 2	Run 3
1	1.76	1.41	1.73
2	2.00	1.37	1.61
3	1.56	1.01	1.57
4	1.88	1.13	1.81
5	1.43	0.91	3.33
6	1.62	0.99	1.39
7	1.54	1.35	1.67
8	1.64	1.04	1.82
9	1.39	1.29	2.05
10	1.45	1.64	1.69
11	2.28	1.48	1.74
12	1.60	1.64	1.59
13	3.46	1.19	2.84
14	2.18	1.57	1.54
15	1.65	1.17	2.09
16	1.54	1.42	2.17
Maximum	3.46	1.64	3.33
Average	1.81	1.29	1.92

Each piston rings' mass changes are shown in Table 10. Over each of the three repeatability runs, average mass change of 0.07 grams was experienced for the top fire ring. Averages for the second ring and oil control ring varied between 0.02 to 0.03 grams.

Table 10 – Repeatability Runs, Ring Mass Changes

Piston Ring Mass Changes (grams)				
Cylinder	Ring No.	Run 1	Run 2	Run 3
1	1	0.0575	0.0510	0.0512
	2	0.0196	0.0236	0.0240
	3	0.0207	0.0150	0.0234
2	1	0.0783	0.0665	0.0574
	2	0.0308	0.0294	0.0261
	3	0.0218	0.0175	0.0184
3	1	0.0716	0.0806	0.0645
	2	0.0277	0.0344	0.0278
	3	0.0244	0.0216	0.0168
4	1	0.0783	0.0542	0.0520
	2	0.0238	0.0188	0.0226
	3	0.0212	0.0164	0.0162
5	1	0.0778	0.0807	0.0911
	2	0.0319	0.0345	0.0282
	3	0.0276	0.0223	0.0190
6	1	0.0840	0.0705	0.0614
	2	0.0268	0.0244	0.0247
	3	0.0213	0.0198	0.0160
7	1	0.0673	0.0879	0.0638
	2	0.0224	0.0344	0.0260
	3	0.0193	0.0205	0.0209
8	1	0.0917	0.1051	0.0475
	2	0.0402	0.0331	0.0192
	3	0.0256	0.0264	0.0164

Maximum mass change, All Cylinders, All Runs	Ring 1	0.1051
	Ring 2	0.0402
	Ring 3	0.0276

Average mass change, All Cylinders, All Runs	Ring 1	0.0705
	Ring 2	0.0273
	Ring 3	0.0204

Although there are no set or published limits for individual metrology measurements, the three run repeatability data should provide a good basis of comparison for variation of "normal" accepted values based on the consistency of control and oil degradation shown between each run. These measurements will be helpful in identifying any unusual trends that might be present during the SCPL evaluations, and identify differences in engine wear at end of test (EOT) conditions between SCPL and baseline runs.

Similar to the engine metrology data, average piston deposits across each of the three repeatability runs were established. Table 11 shows the average deposit demerits for each of the three runs. The average value shown for each run is calculated from the individual averages of each cylinder. A composite average of all three runs was also included to serve as a basis of comparison. Similar to the metrology, there are no predefined limits for identifying excessive deposit formation for this engine and test cycle. What this will provide again is a consistent baseline of comparison between each of the SCPL and baseline runs. Critical parameters of interest are ring condition and overall piston deposits.

Table 11 – Repeatability Runs, Piston & Valve Ratings

Piston Deposits				
Ratings	Cylinder Average			3 Run Average
	Run 1	Run 2	Run 3	
Ring Sticking				
Ring No.1	No	No	No	No
Ring No.2	No	No	No	No
Ring No.3	No	No	No	No
Scuffing % Area				
Ring No.1	0	0	0	0.00
Ring No.2	0	0	0	0.00
Ring No.3	0	0	0	0.00
Piston Crown	0	0	0	0.00
Piston Skirt	0	0	0	0.00
Cylinder Liner, %	0	0	0	0.00
Piston Carbon, Demerits				
No.1 Groove	65.84	41.31	44.63	50.59
No.2 Groove	3.16	6.32	6.75	5.41
No.3 Groove	0.00	0.00	0.00	0.00
No.1 Land	53.25	39.41	47.41	46.69
No.2 Land	10.53	18.59	18.66	15.93
No.3 Land	0.25	1.38	0.38	0.67
Upper Skirt	0.00	0.00	0.00	0.00
Under Crown	1.25	1.56	0.00	0.94
Front Pin Bore	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits				
No.1 Groove	0.00	0.00	0.00	0.00
No.2 Groove	2.92	2.80	2.66	2.79
No.3 Groove	1.80	2.96	1.76	2.17
No.1 Land	0.10	0.31	0.20	0.20
No.2 Land	1.92	1.47	1.29	1.56
No.3 Land	1.93	2.71	2.11	2.25
Upper Skirt	0.64	1.29	0.81	0.91
Under Crown	3.17	4.06	3.34	3.52
Front Pin Bore	1.28	1.41	1.21	1.30
Rear Pin Bore	1.29	1.54	1.41	1.41
Total, Demerits	149.32	127.10	132.60	136.34
Miscellanous				
Top Groove Fill, %	63.13	37.13	40.88	47.04
Intermediate Groove Fill, %	1.00	2.13	1.50	1.54
Top Land Heavy Carbon, %	38.13	21.88	32.88	30.96
Top Lan Flaked Carbon, %	0.00	0.00	0.38	0.13
Valve Tulip Deposits, Merits				
Exahust	9.0	9.0	9.1	9.04
Intake	7.2	8.5	6.7	7.46

Full test report data for MIL-PRF-46167D repeatability runs 1, 2 and 3 can be seen in Appendix A1, A2, and A3 respectively.

3.2.5 MIL Specification and Commercial Lubricant Evaluations

To determine SCPL candidate performance to lubricants used by the military, GEP 6.5L(T) high temperature oil endurance tests were completed using MIL-PRF-2104G and MIL-PRF-2104H OE/HDO SAE 15W-40 engine oils. In addition, a commercially available petroleum based API performance classification CJ-4 SAE 15W-40 was evaluated to benchmark SCPL and military lubricants against current industry available lubricants. Testing was completed in accordance to the previously stated guidelines, and operated identically to the MIL-PRF-46167D OEA-30 repeatability test runs. Table 12 shows the engine operating summary for each MIL specification and commercial runs during the rated speed and load step. As before, this data is derived from an average value of each critical test point over the entire time spent at rated conditions. This shows the consistency of engine control achieved during the evaluation tests compared to the 3-run repeatability testing.

Table 12 – MIL Specification & Commercial Lubricant Evaluations, Rated Engine Operating Summary

		MIL-PRF-2104G **Rated Conditions (3400 RPM)**		MIL-PRF-2104H **Rated Conditions (3400 RPM)**		Commercial CJ-4 **Rated Conditions (3400 RPM)**	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.02	0.79	3400.03	0.71	3400.01	0.75
Torque*	Lb*ft	255.39	1.91	255.65	1.59	254.83	2.32
Fuel Flow	lb/hr	80.30	0.86	78.63	1.18	80.15	1.18
Power*	bhp	165.33	1.22	165.51	1.01	164.97	1.50
BSFC*	lb/bhp*hr	0.486	0.006	0.475	0.008	0.486	0.009
Temperatures:							
Coolant In	°F	190.84	0.67	191.39	1.05	191.01	1.01
Coolant Out	°F	204.99	0.61	204.99	0.96	204.99	0.94
Oil Sump	°F	260.01	1.15	260.15	0.71	260.07	0.81
Fuel In	°F	95.27	0.88	95.00	0.36	95.01	0.34
Intake Air	°F	68.99	1.87	62.95	10.05	61.21	3.53
Cylinder 1 Exhaust	°F	1129.50	16.49	976.82	27.28	1027.38	25.21
Cylinder 2 Exhaust	°F	1198.55	9.85	1038.54	32.21	1054.01	29.41
Cylinder 3 Exhaust	°F	1196.31	10.84	1060.20	33.06	1083.30	18.51
Cylinder 4 Exhaust	°F	1119.81	12.52	1030.32	26.52	1064.49	27.69
Cylinder 5 Exhaust	°F	1136.14	9.87	1097.57	33.08	1128.62	20.75
Cylinder 6 Exhaust	°F	1142.53	13.50	1068.33	26.94	1111.43	25.56
Cylinder 7 Exhaust	°F	1123.31	11.20	1017.64	26.96	1084.31	26.61
Cylinder 8 Exhaust	°F	1152.38	9.48	1092.78	34.95	1103.24	23.86
Pressures:							
Oil Galley	psi	41.85	0.91	43.63	1.49	45.60	1.57
Ambient Pressure	psiA	14.23	0.04	14.40	0.14	14.34	0.11
Boost Pressure	psi	4.60	0.06	4.85	0.09	5.00	0.09

* Non-corrected Values

MIL-PRF-2104G (previous military standard OE/HDO) was used by the military through approximately July 2004 when it was superseded by MIL-PRF-2104H. During testing it was found that MIL-PRF-2104H achieved large improvements in overall oxidation resistance by nearly doubling the total capable time of testing over MIL-PRF-2104G. Figure 6 shows the TAN/TBN response for all of the MIL specification and commercial lubricant evaluations. Surprisingly, the commercial petroleum based SAE 15W-40 handily outperformed both of the military specification lubricants. This type of performance is what the Army wants to identify and incorporate into the SCPL lubricants, and this test helped identify this particular shortcoming of the current MIL specification lubricant lineup.

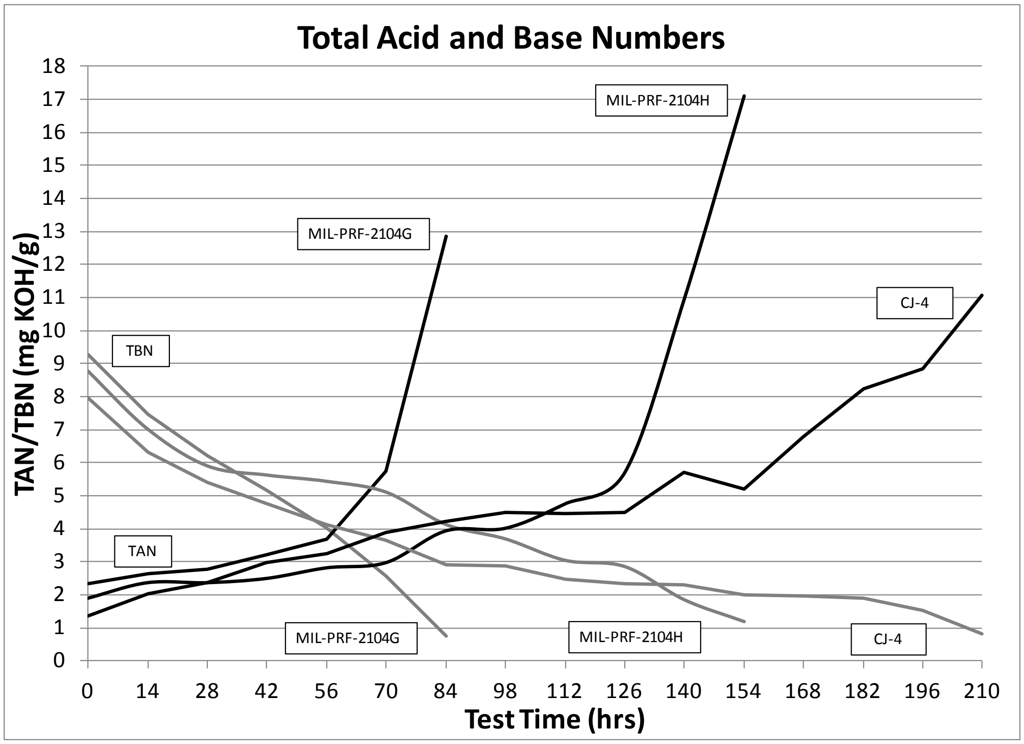


Figure 6 – MIL Specification & Commercial Lubricant Evaluations, TAN/TBN Response

Figure 7 shows the lead and copper accumulation for the MIL specification and commercial evaluations. During the MIL-PRF-2104G testing, as soon as TAN and TBN crossed, overall oil degradation would generally accelerate rapidly. This attributes to the overall lack of test hours that can be accumulated prior to breaking the oil. In contrast, both the MIL-PRF-2104H and commercial SAE 15W-40 shows improved stability after the TAN/TBN cross which allows longer test durations before oil degradation sets in. The current SAE 15W-40 OE/HDO specification, MIL-PRF-2104H, generally shows equivalent performance to the MIL-PRF-46167D OEA-30. Unfortunately both MIL specification lubricants fall short of the capabilities seen of the commercial petroleum based SAE 15W-40 lubricant.

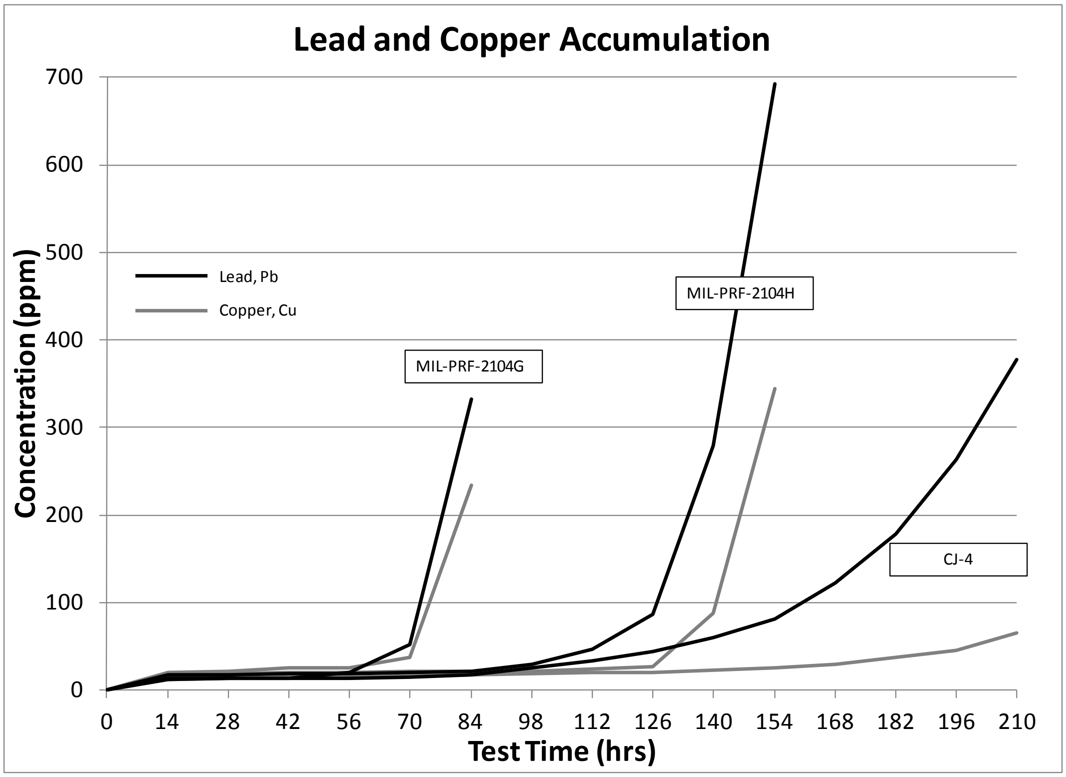


Figure 7 – MIL Specification & Commercial Lubricant Evaluations, Lead and Copper Accumulation

Similar to the TAN/TBN and wear metal plots, Figure 8 shows the oxidation and nitration response of the MIL specification and commercial lubricant evaluations. Again there was improvement in the MIL-PRF-2104H oil in overall oxidation stability compared to the 2104G, but it still experienced aggressive degradation early in the test compared to the commercial petroleum based SAE 15W-40.

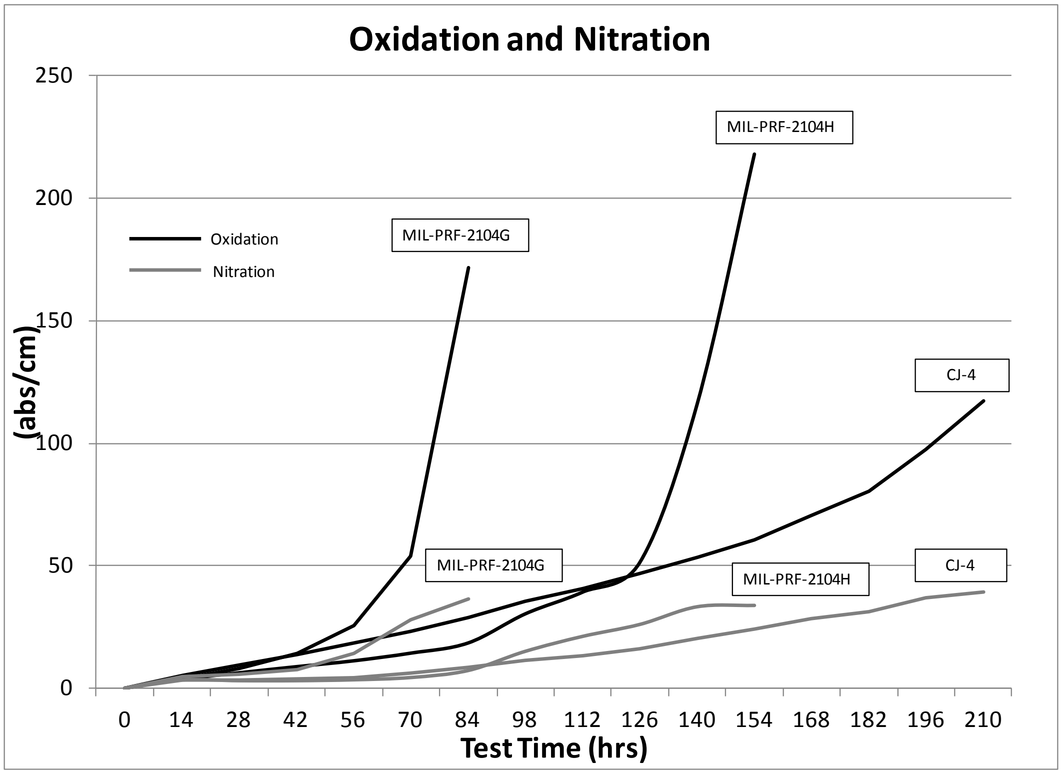


Figure 8 – MIL Specification & Commercial Lubricant Evaluations, Oxidation and Nitration Response

Table 13 shows the accumulated oil consumption rates for the MIL specification and commercial runs. Overall hourly consumption rates were in line with what was seen during the repeatability runs, with the commercial petroleum based SAE 15W-40 oil showing a slightly higher consumption rate.

Table 13 – MIL Specification & Commercial Lubricant Evaluations, Accumulated Oil Consumption Rate

	MIL-PRF-2104G	MIL-PRF-2104H	Commercial CJ-4 15W-40
Engine Oil Consumption [lb/hr]	**0.081**	**0.069**	**0.090**

Table 14 shows the main bearing mass changes for the baseline MIL specification and commercial oil testing. Like the repeatability runs using OEA-30, the number three thrust bearing mass was omitted from calculation to not bias data from varying thrust load wear on the engine due to dyno and coupling interactions. Average weight changes for each of the tests range between 0.03 to 0.15 grams. This compared to the 0.03 to 0.06 gram variation seen in the three OEA-30 repeatability runs shows similar performance overall. At face value, the MIL-PRF-2104H evaluation, which had over twice the main bearing weight loss of the worst OEA-30 repeatability run, looks to show poor performance. But when considering the EOT wear metal accumulation, it was the only run that had lead concentrations over 600 ppm. Overall, none of the main bearing mass changes were alarming, and each corresponded well to each tests individual EOT oil condition and total number of test hours.

Table 14 – MIL Specification & Commercial Lubricant Evaluations, Main Bearing Mass Changes

Main Bearing Mass Changes (grams)				
Main Bearing	**Shell**	**2104G**	**2104H**	**CJ-4**
1	Top	0.0225	0.1528	0.2208
	Bottom	0.0196	0.0534	0.0516
2	Top	0.0136	0.1224	0.1265
	Bottom	0.0378	0.1958	0.0642
3	Thrust Bearing Excluded From Calculations			
4	Top	0.0110	0.0387	0.0899
	Bottom	0.0297	0.1114	0.0493
5	Top	0.0464	0.1189	0.0672
	Bottom	0.0422	0.3821	0.0810
	Maximum	0.0464	0.3821	0.2208
	Average	0.0278	0.1469	0.0938

Table 15 shows the connecting rod bearing mass changes for MIL specification and commercial lubricant evaluations. As with the main bearing mass changes, direct comparisons cannot be made. Regardless, total connecting rod bearing mass variation for the MIL specification and commercial lubricant evaluations ranged from 0.02 to 0.03 grams, which falls in line with the 0.03 to 0.04 variation seen during repeatability testing.

Table 15 – MIL Specification & Commercial Lubricant Evaluations, Connecting Rod Bearing Mass Changes

Rod Bearing Mass Changes (grams)				
Rod Bearing	Shell	2104G	2104H	CJ-4
1	Top	0.0257	0.0168	0.0155
	Bottom	0.0945	0.0372	0.0199
2	Top	0.0313	0.0136	0.0286
	Bottom	0.0190	0.0177	0.0199
3	Top	0.0079	0.0181	0.0252
	Bottom	0.0116	0.0161	0.0179
4	Top	0.0082	0.0516	0.0221
	Bottom	0.0137	0.0290	0.0204
5	Top	0.0267	0.0206	0.0208
	Bottom	0.0816	0.0604	0.0134
6	Top	0.0217	0.0356	0.0164
	Bottom	0.0247	0.0303	0.0174
7	Top	0.0161	0.0149	0.0180
	Bottom	0.0401	0.0485	0.0236
8	Top	0.0083	0.0235	0.0200
	Bottom	0.0529	0.0454	0.0191

Maximum	0.0945	0.0604	0.0286
Average	0.0303	0.0300	0.0199

Table 16 shows the camshaft lobe peak surface variation for each of the MIL specification and commercial lubricant evaluations. Total variation seen during testing ranged from 1.4 to 1.6 microns. This variance falls within the range of the average variation seen during repeatability testing.

Table 16 – MIL Specification & Commercial Lubricant Evaluations, Cam Lobe Peak Surface Variation

Cam Lobe Waviness Parameter (μm)			
Cam Lobe	2104G	2104H	CJ-4
1	1.79	1.24	2.00
2	1.33	1.22	2.15
3	1.41	1.04	1.39
4	1.19	1.44	1.72
5	1.53	1.13	1.54
6	1.48	1.12	1.98
7	1.75	1.34	1.38
8	1.53	1.64	1.27
9	1.38	1.09	1.56
10	1.62	1.42	1.57
11	1.25	1.02	1.28
12	1.31	1.51	1.28
13	1.27	1.20	1.80
14	1.40	1.83	1.89
15	1.21	1.44	1.75
16	1.61	2.17	1.28
Maximum	1.79	2.17	2.15
Average	1.44	1.37	1.62

Table 17 shows the ring pack mass loss for each of the MIL specification and commercial lubricant evaluations. Average weight loss for the first ring for each test was in the 0.05 gram range, and between 0.02 and 0.03 grams for the second and oil control ring. These mass changes were slightly less than that seen during the repeatability runs. This tends to indicates that some increased ring wear may be introduced with the lower viscosity lubricant, but nothing can be definitively said due to different total times of engine operation on test.

Table 17 – MIL Specification & Commercial Lubricant Evaluations, Piston Ring Mass Changes

Piston Ring Mass Changes (grams)				
Cylinder	**Ring No.**	**2104G**	**2104H**	**CJ-4**
1	1	0.0407	0.0428	0.0508
	2	0.0213	0.0176	0.0225
	3	0.0159	0.0122	0.0135
2	1	0.0458	0.0402	0.0521
	2	0.0183	0.0241	0.0298
	3	0.0125	0.0153	0.0167
3	1	0.0570	0.0563	0.0581
	2	0.0208	0.0325	0.0347
	3	0.0152	0.0181	0.0192
4	1	0.0434	0.0413	0.0541
	2	0.0167	0.0244	0.0254
	3	0.0144	0.0153	0.0168
5	1	0.0448	0.0615	0.0627
	2	0.0244	0.0276	0.0303
	3	0.0143	0.0160	0.0174
6	1	0.0508	0.0701	0.0802
	2	0.0217	0.0264	0.0348
	3	0.0144	0.0158	0.0214
7	1	0.0477	0.0456	0.0530
	2	0.0193	0.0279	0.0223
	3	0.0112	0.0162	0.0146
8	1	0.1122	0.0642	0.0539
	2	0.0420	0.0272	0.0299
	3	0.0271	0.0161	0.0204

Maximum Ring 1	0.1122	0.0701	0.0802
Maximum Ring 2	0.0420	0.0325	0.0348
Maximum Ring 3	0.0271	0.0181	0.0214

Average Ring 1	0.0553	0.0527	0.0581
Average Ring 2	0.0231	0.0260	0.0287
Average Ring 3	0.0156	0.0156	0.0175

Lastly, Table 18 shows the piston ratings for each of the MIL specification and commercial lubricant evaluations. Total demerits ranged between 120-158 compared to the 127-149 seen during the repeatability testing. Percentages for top and intermediate groove fill are similar, if not slightly worse, to those seen during the repeatability runs. Despite this, none of the deposits seen would be considered excessive and harmful to engine operation.

Full test report data for MIL-PRF-2104G, MIL-PRF-2104H, and the commercial petroleum based SAE 15W-40 oil can be seen in Appendix B1, B2, and B3 respectively.

Table 18 – MIL Specification & Commercial Lubricant Evaluations, Piston Deposits

Piston Deposits			
Ratings	Cylinder Average		
	2104G	2104H	CJ-4
Ring Sticking			
Ring No.1	No	No	No
Ring No.2	No	No	No
Ring No.3	No	No	No
Scuffing % Area			
Ring No.1	0	0	0
Ring No.2	0	0	0
Ring No.3	0	0	0
Piston Crown	0	0	0
Piston Skirt	0	0	0
Cylinder Liner, %	0	0	0
Piston Carbon, Demerits			
No.1 Groove	33.00	54.19	59.13
No.2 Groove	11.75	13.56	12.91
No.3 Groove	0.00	0.00	0.00
No.1 Land	34.06	42.22	40.28
No.2 Land	21.81	18.31	25.94
No.3 Land	1.38	1.69	1.75
Upper Skirt	0.00	0.00	0.00
Under Crown	0.47	3.91	3.91
Front Pin Bore	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00
Piston Lacquer, Demerits			
No.1 Groove	0.00	0.12	0.00
No.2 Groove	2.66	3.38	2.24
No.3 Groove	2.33	2.87	1.61
No.1 Land	0.03	0.06	0.07
No.2 Land	1.28	1.80	0.77
No.3 Land	3.60	3.54	2.06
Upper Skirt	0.50	0.78	0.71
Under Crown	4.79	4.05	4.24
Front Pin Bore	1.42	1.40	1.30
Rear Pin Bore	1.33	1.48	1.25
Total, Demerits	120.40	153.35	158.15
Miscellanous			
Top Groove Fill, %	25.25	45.75	51.50
Intermediate Groove Fill, %	8.38	10.88	6.00
Top Land Heavy Carbon, %	14.13	23.88	21.25
Top Lan Flaked Carbon, %	0.00	0.13	0.00
Valve Tulip Deposits, Merits			
Exahust	9.2	9.3	9.0
Intake	8.3	6.7	7.2

3.2.6 Candidate Evaluation Results

From the preliminary testing, a clear picture of current MIL specification lubricant performance and selected industry performance was defined. This allowed for any improvement in SCPL candidates to be easily identified when compared to baseline runs. Table 19 shows the engine operating summary for each SCPL candidate run during the rated speed and load step. This once again shows the consistency that was achieved during the evaluation tests compared to the 3-run repeatability and baseline testing. For candidate LO253071, the overall torque average was slightly below the target 256 lbft, but within the +/- 5 lbft margin. Due to variation in engine output between each production engine, some engines where only marginally meeting the 256 lbft target at the start of testing, and upon oil aging and thickening within the crankcase, engine output power/torque would begin to drop below the threshold that could be adjusted. A 5 lbft variation in engine output is not considered to have any biasing effect in overall oil durability data.

Table 19 – SCPL Candidate Evaluations, Rated Engine Operation Summary

		LO253071 Rated Conditions (3400 RPM)		LO254054 Rated Conditions (3400 RPM)		LO25033 Rated Conditions (3400 RPM)		LO251746 Rated Conditions (3400 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.02	0.82	3400.01	1.17	3400.01	0.75	3400.00	0.72
Torque*	ft*lb	251.40	4.43	254.59	2.06	253.87	2.99	256.24	1.74
Fuel Flow	lb/hr	82.51	1.06	81.41	1.58	82.82	1.29	77.86	0.89
Power*	bhp	162.74	2.87	164.82	1.32	164.36	1.93	165.88	1.11
BSFC*	lb/bhp*hr	0.507	0.012	0.494	0.011	0.504	0.011	0.469	0.006
Temperatures:									
Coolant In	°F	190.31	0.92	191.33	0.57	190.84	0.75	191.39	0.73
Coolant Out	°F	205.00	0.84	205.00	0.53	205.00	0.70	204.99	0.66
Oil Sump	°F	260.02	0.41	259.96	0.91	260.04	0.37	259.96	0.37
Fuel In	°F	95.00	0.31	95.41	1.03	95.09	0.50	95.01	0.33
Intake Air	°F	69.72	4.99	69.82	2.24	64.19	3.89	69.95	2.24
Cylinder 1 Exhaust	°F	1148.60	9.38	1128.23	29.43	1095.59	31.46	1098.38	14.59
Cylinder 2 Exhaust	°F	1104.56	14.95	1113.31	20.14	1082.53	18.05	1158.88	18.88
Cylinder 3 Exhaust	°F	1216.91	13.84	1198.94	15.99	1123.25	50.99	1224.78	31.99
Cylinder 4 Exhaust	°F	1158.22	17.08	1122.02	23.03	1136.45	14.02	1115.13	16.48
Cylinder 5 Exhaust	°F	1173.29	9.48	1132.85	27.40	1168.95	26.40	1181.29	25.83
Cylinder 6 Exhaust	°F	1206.17	21.87	1158.50	29.60	1197.56	14.82	1118.51	17.07
Cylinder 7 Exhaust	°F	1133.30	10.52	1099.28	23.83	1149.01	25.70	1123.50	19.87
Cylinder 8 Exhaust	°F	1189.49	23.12	1163.36	24.85	1170.32	15.13	1144.84	18.46
Pressures:									
Oil Galley	psi	34.70	0.74	34.04	1.02	41.50	1.25	37.13	0.99
Ambient Pressure	psiA	14.25	0.05	14.29	0.04	14.31	0.11	14.23	0.04
Boost Pressure	psi	4.95	0.11	4.78	0.10	5.31	0.21	3.96	0.09

* Non-corrected Values

Figure 9 shows the TAN/TBN response of each candidate. SCPL candidate LO254054 showed overall poor performance, similar to that seen during the MIL-PRF-2104G testing. TAN/TBN cross over occurred early in the test, and the oil immediately broke and rapid degradation set in. SCPL candidate LO23071, which was a lower viscosity reformulation based off the MIL-PRF-46167 OEA-30 showed slightly reduced performance from the OEA-30 repeatability testing. This was overall disappointing since it was the closest product to lubricants currently used in the military. Candidates LO251746 and LO25033 both successfully completed 168 hours before testing was terminated. In retrospect, testing could have continued longer for both of these lubricants. Their EOT used oil conditions were mild in comparison to most other SCPL evaluations. Despite this, additional testing would not have been expected much past an added 14 hours.

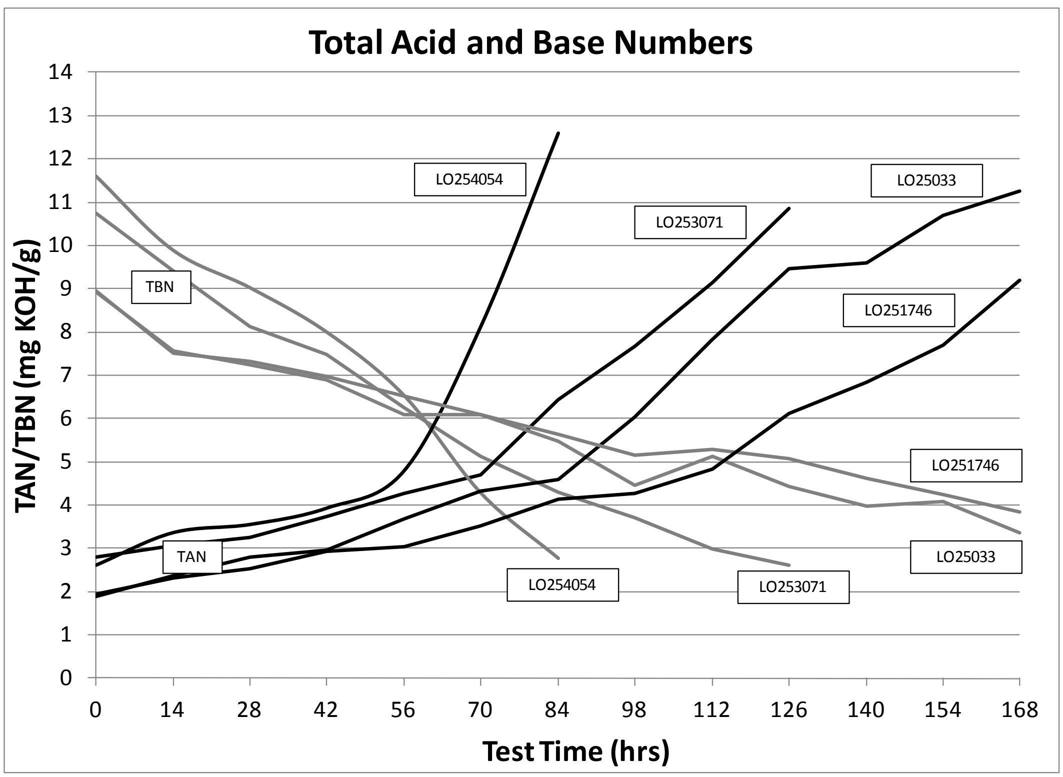


Figure 9 – SCPL Candidate Evaluations, TAN/TBN Response

Like the TAN/TBN results, the oxidation and nitration curves shown in Figure 10 show similar trends. Candidate LO254045 broke early and experienced rapid oxidation between 56 and 84 hours of testing. The remaining candidates showed an increased stability after TAN/TBN cross and showed slightly steadier oxidation rates throughout testing. Again candidates LO25033 and LO251746 showed the best performance. These two candidates, supplied by one supplier, appeared very similar in formulation, with variation primarily in viscometric properties.

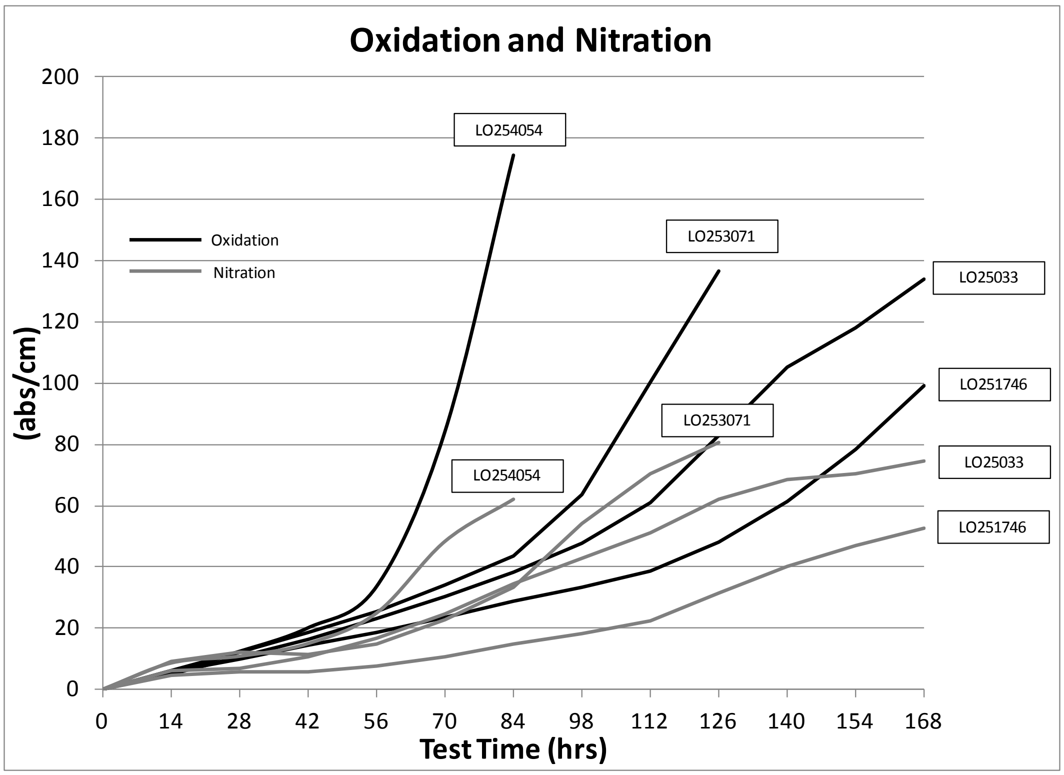


Figure 10 – SCPL Candidate Evaluations, Oxidation and Nitration Response

Figure 11 shows the lead and copper wear metal accumulations during the SCPL evaluations. Again, candidates LO25033 and LO251746 showed the best performance. Of the two, candidate LO251746 showed the lowest critical wear metal accumulations from all the tests completed. Candidates LO253071 and LO254054, which were also supplied by one supplier, fell short of desired performance, but gave valuable insight to the formulators into what the SCPL lubricant required to perform under these severe duty conditions.

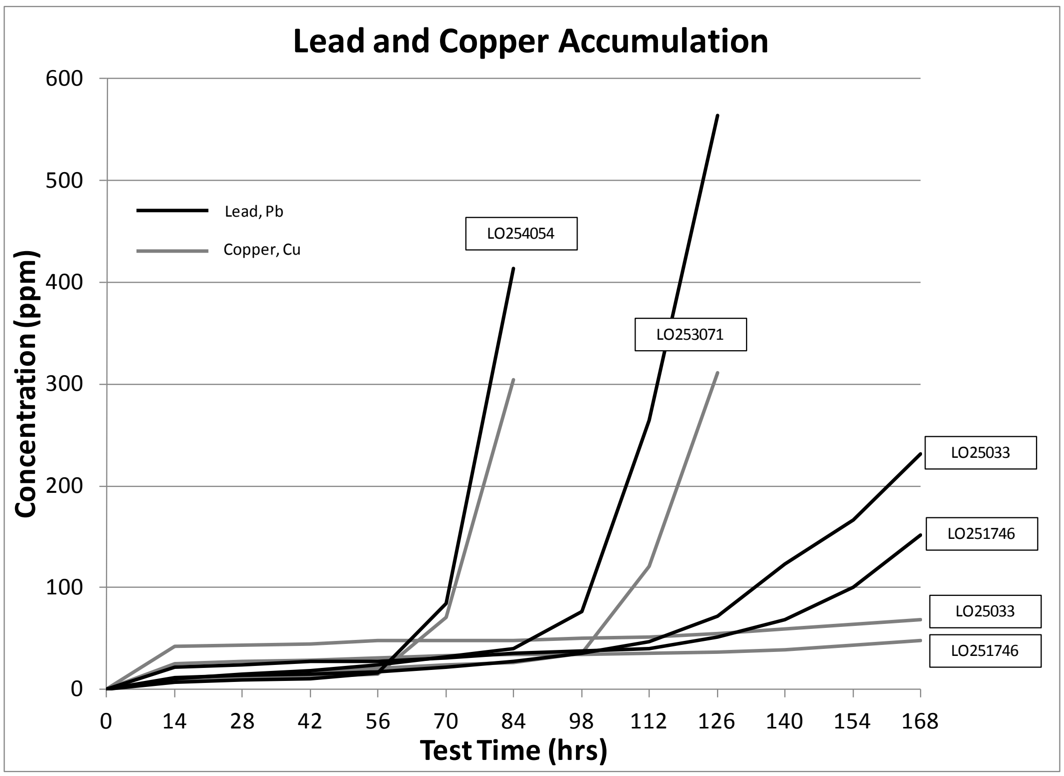


Figure 11 – SCPL Candidate Evaluations, Lead and Copper Accumulation

Table 20 shows the accumulated oil consumption rates for the SCPL evaluation runs. Overall hourly consumption rates were in line with what was seen previously, with candidate LO25033 showing the highest consumption rate of any single test.

Table 20 – SCPL Candidate Evaluations, Accumulated Oil Consumption Rate

	LO253071	LO254054	LO25033	LO251746
Engine Oil Consumption [lb/hr]	**0.069**	**0.064**	**0.098**	**0.072**

Table 21 shows the main bearing mass changes for each of the SCPL evaluations. As before, the number three thrust bearing mass is omitted from calculations. Average weight changes for each of the tests range between 0.03 to 0.05 grams. This compared to the 0.03 to 0.06 gram variation seen in the three OEA-30 repeatability runs, and the 0.03 to 0.15 gram variation seen in the MIL specification and commercial tests, is a good fit overall.

Table 21 – SCPL Candidate Evaluations, Main Bearing Mass Changes

Main Bearing Mass Changes (grams)					
Main Bearing	**Shell**	**LO253071**	**LO254054**	**LO25033**	**LO251746**
1	Top	0.0171	0.0145	0.0283	0.0257
	Bottom	0.0146	0.0134	0.0276	0.0237
2	Top	0.0205	0.0149	0.0286	0.0240
	Bottom	0.0891	0.0582	0.0843	0.0338
3	Thrust Bearing Excluded From Calculations				
4	Top	0.0124	0.0183	0.0200	0.0293
	Bottom	0.0385	0.0257	0.0533	0.0305
5	Top	0.0777	0.0553	0.0418	0.0411
	Bottom	0.1066	0.0606	0.0691	0.0830

Maximum	0.1066	0.0606	0.0843	0.0830
Average	0.0471	0.0326	0.0441	0.0364

Table 22 shows the connecting rod bearing mass changes for SCPL candidate evaluations. Total connecting rod bearing mass variation for the SCPL evaluations ranged from 0.02 to 0.04 grams, which is in line with the 0.03 to 0.04 gram variation seen during the repeatability testing, and the 0.02 and 0.04 gram variation in the MIL specification and commercial lubricant tests.

Table 22 – SCPL Candidate Evaluations, Connecting Rod Bearing Mass Changes

Rod Bearing Mass Changes (grams)					
Rod Bearing	**Shell**	**LO253071**	**LO254054**	**LO25033**	**LO251746**
1	Top	0.1668	0.0111	0.0235	0.0339
	Bottom	0.0598	0.0245	0.0133	0.0347
2	Top	0.0289	0.0248	0.0171	0.0147
	Bottom	0.0374	0.0062	0.0163	0.0177
3	Top	0.0520	0.0117	0.0148	0.0239
	Bottom	0.0540	0.0056	0.0149	0.0290
4	Top	0.0135	0.0138	0.0115	0.0431
	Bottom	0.0082	0.0319	0.0088	0.0695
5	Top	0.0316	0.0358	0.0171	0.0158
	Bottom	0.0612	0.0340	0.0141	0.0155
6	Top	0.0338	0.0216	0.0128	0.0454
	Bottom	0.0342	0.0224	0.0093	0.0703
7	Top	0.0139	0.0287	0.0318	0.0664
	Bottom	0.0188	0.0174	0.0190	0.0564
8	Top	0.0115	0.0123	0.0156	0.0416
	Bottom	0.0098	0.0215	0.0121	0.0542
	Maximum	0.1668	0.0358	0.0318	0.0703
	Average	0.0397	0.0202	0.0158	0.0395

Table 23 shows the camshaft lobe peak surface variation for each of the SCPL candidate evaluations. With the exception of candidate LO253071, total variation seen during testing from each SCPL ranged from 1.5 to 1.8 microns. This variance falls within the max and min of average variation seen in all previous testing. On the other hand, SCPL candidate LO253071 showed an average variation of 3.1 microns. This was consistent over all of the lobes, and indicates this candidate may be prone to increased camshaft and roller follower wear rates. Further testing specifically targeting this pattern would need to be conducted to fully understand the phenomenon.

Table 23 – SCPL Candidate Evaluations, Cam Lobe Peak Surface Variation

Cam Lobe Waviness Parameter (µm)				
Cam Lobe	LO253071	LO254054	LO25033	LO251746
1	3.49	2.32	1.39	1.74
2	3.00	1.23	1.66	1.47
3	3.80	1.55	1.33	1.60
4	2.79	2.91	1.33	1.58
5	2.24	1.20	1.16	1.38
6	2.40	1.15	1.65	1.94
7	2.78	1.59	1.46	1.46
8	3.37	1.79	1.70	2.25
9	5.34	1.45	1.51	1.53
10	2.97	1.35	1.51	1.92
11	2.39	1.22	1.74	1.41
12	4.16	1.45	1.98	3.33
13	3.04	1.09	1.61	1.72
14	2.44	1.66	2.20	1.49
15	3.10	1.27	2.08	1.54
16	2.06	1.56	2.46	1.67
Maximum	5.34	2.91	2.46	3.33
Average	3.09	1.55	1.67	1.75

Table 24 shows the ring pack mass loss for each of the SCPL candidate evaluations. Average weight loss for the first ring for each test was in the 0.06 to 0.09 gram range, and between 0.02 to 0.03 grams for the second and oil control ring (Note: for candidate LO251746 piston number 8 oil control ring, mass loss shows as 0.5625 grams. This appears to be an isolated anomaly, and is not representative of the remaining oil control rings changes on pistons 1 through 7). These variation, much like the repeatability runs, appear to be larger overall than what was seen during the various SAE 15W-40 oils tested during the MIL specification and commercial lubricant evaluations. Again this tends to indicate some increased ring wear may be due to the lower viscosity, but is not definitive due to the variation in test length.

Table 24 – SCPL Candidate Evaluations, Piston Ring Mass Changes

Piston Ring Mass Changes (grams)					
Cylinder	Ring No.	LO253071	LO254054	LO25033	LO251746
1	1	0.0678	0.0567	0.0692	0.0768
	2	0.0241	0.0191	0.0311	0.0260
	3	0.0160	0.0139	0.0151	0.0154
2	1	0.0661	0.0605	0.0933	0.0875
	2	0.0290	0.0240	0.0358	0.0262
	3	0.0160	0.0139	0.0200	0.0135
3	1	0.0790	0.0570	0.1132	0.0914
	2	0.0342	0.0243	0.0441	0.0247
	3	0.0198	0.0152	0.0229	0.0167
4	1	0.0676	0.0580	0.0845	0.0857
	2	0.0252	0.0260	0.0309	0.0273
	3	0.0163	0.0191	0.0164	0.0191
5	1	0.0740	0.0598	0.0792	0.0786
	2	0.0261	0.0208	0.0321	0.0264
	3	0.0182	0.0129	0.0183	0.0190
6	1	0.0993	0.0633	0.1074	0.0937
	2	0.0328	0.0224	0.0372	0.0277
	3	0.0223	0.0163	0.0195	0.0173
7	1	0.0635	0.0580	0.0874	0.0905
	2	0.0256	0.0193	0.0355	0.0236
	3	0.0188	0.0137	0.0179	0.0129
8	1	0.0828	0.0720	0.0989	0.0716
	2	0.0277	0.0169	0.0429	0.0268
	3	0.0186	0.0167	0.0186	0.5625

Maximum Ring 1	0.0993	0.0720	0.1132	0.0937
Maximum Ring 2	0.0342	0.0260	0.0441	0.0277
Maximum Ring 3	0.0223	0.0191	0.0229	0.5625

Average Ring 1	0.0750	0.0607	0.0916	0.0845
Average Ring 2	0.0281	0.0216	0.0362	0.0261
Average Ring 3	0.0183	0.0152	0.0186	0.0846

Lastly, Table 25 shows the piston ratings for each of the SCPL candidate evaluations. Total demerits ranged between 105-156. With the exception of LO25033 at 156 demerits, the remaining candidates accumulated less than 110 total which tends to indicate an increased ability of the SCPL candidates to control deposit formation in the engine. This is likely directly linked to their particular formulations. None of the deposits seen during these tests, including candidate LO25033, would be considered excessive and harmful to engine operation.

Full test report data from each candidate tests, LO253071, LO254054, LO25033, and LO251746 can be seen in Appendix C1, C2, C3, and C4 respectively.

Table 25 – SCPL Candidate Evaluations, Piston Deposits

Piston Deposits				
Ratings	**Cylinder Average**			
	LO253071	LO254054	LO25033	LO251746
Ring Sticking				
Ring No.1	No	No	No	No
Ring No.2	No	No	No	No
Ring No.3	No	No	No	No
Scuffing % Area				
Ring No.1	0	0	0	0
Ring No.2	0	0	0	0
Ring No.3	0	0	0	0
Piston Crown	0	0	0	0
Piston Skirt	0	0	0	0
Cylinder Liner, %	0	0	0	0
Piston Carbon, Demerits				
No.1 Groove	43.88	36.69	73.84	36.28
No.2 Groove	0.66	2.72	6.63	5.84
No.3 Groove	0.31	0.00	0.25	0.00
No.1 Land	36.50	35.56	38.66	36.31
No.2 Land	11.69	14.97	19.94	14.25
No.3 Land	0.00	1.38	0.88	0.88
Upper Skirt	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00
Front Pin Bore	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits				
No.1 Groove	0.00	0.00	0.00	0.00
No.2 Groove	3.17	2.48	2.88	2.73
No.3 Groove	2.57	1.41	1.30	1.41
No.1 Land	0.05	0.03	0.01	0.02
No.2 Land	1.89	2.25	1.10	2.20
No.3 Land	2.37	2.00	2.31	1.21
Upper Skirt	0.34	0.29	0.40	0.54
Under Crown	2.95	3.07	5.58	4.77
Front Pin Bore	1.26	1.25	1.31	0.80
Rear Pin Bore	1.20	1.25	1.26	0.74
Total, Demerits	108.84	105.35	156.35	107.98
Miscellanous				
Top Groove Fill, %	38.63	32.13	72.38	28.50
Intermediate Groove Fill, %	0.00	0.75	3.75	2.13
Top Land Heavy Carbon, %	18.38	16.25	18.63	16.38
Top Lan Flaked Carbon, %	0.00	0.13	0.00	0.00
Valve Tulip Deposits, Merits				
Exahust	9.2	9.1	9.1	9.0
Intake	8.6	8.3	7.6	8.6

3.3 TRANSMISSION COMPATIBILITY

In addition to engine crankcase applications, the SCPL must be capable of being used in military power shift transmission applications. To assess the SCPL candidate performance in these applications, several industry standard transmission test procedures were completed, including selected: Allison C4, Caterpillar TO-4, and John Deere JDQ test procedures. Many of these industry transmission frictional tests utilize an SAE No. 2 friction testing machine. This machine measures the engagement properties of one friction and reaction plate over a wide range of speeds and application forces. It instantaneously records multiple parameters including load applied, torque transmitted, and plate speed to determine overall torque capacity, dynamic and static coefficients of friction, and slip time. Results are then compared to a baseline fluid which brackets desired performance and determines pass fail of a candidate fluid. Results for the SCPL testing are summarized below.

3.3.1 Allison C4 Testing

Allison C4 transmission compatibility evaluations included frictional testing on paper and graphite materials, as well as seal compatibility testing on a number of different elastomeric materials typically used in dynamic and static seal construction. Table 26 shows the results from the seal compatibility portion of the test. All of the candidates provided met each of the seal test criteria except for the N1 (Nitrile) elastomer. Each candidate experienced a negative volume change on the N1 test which fell outside the 0 to 5 percent volume increase allowed. From an industry perspective, this is not an uncommon phenomenon, as the reference oil typically falls just within the limits of the test. This material is typically the most finicky of the elastomer tests. Other specifications, such as Dexron, do not have pass fail limits for nitrile, and instead is listed as “rate and report”. For the SCPL candidates, this may indicate nitrile based seals could potentially experience some degree of contraction.

Table 26 – SCPL Candidate Evaluations, Allison C4 Seal Compatibility

	C4 Seal Test			
Oil Code	**LO250033**	**LO251746**	**LO253071**	**LO254054**
Date	20100810	20100810	20100810	20100810
Elastomer	V1 A-7-0060-85-ETI			
Volume Change, %				
3 Run Candidate Average	8.57	8.9	9.93	7.06
Limits	0.00 to 20.00	0.00 to 20.00	0.00 to 20.00	0.00 to 20.00
Hardness Change, pts				
3 Run Candidate Average	-3	-3	-3	-2
Limits	-15 to 0	-15 to 0	15 to 0	-15 to 0
Elastomer	V2 P-250			
Volume Change, %				
3 Run Candidate Average	5.71	5.48	6.4	5.31
Limits	0.00 to 12.00	0.00 to 12.00	0.00 to 12.00	0.00 to 12.00
Hardness Change, pts				
3 Run Candidate Average	1	-1	0	-1
Limits	-7 to 3	-7 to 3	-7 to 3	-7 to 3
Elastomer	V3 FM-L-69			
Volume Change, %				
3 Run Candidate Average	8.94	8.02	9.55	7.48
Limits	0.00 to 22.00	0.00 to 22.00	0.00 to 22.00	0.00 to 22.00
Hardness Change, pts				
3 Run Candidate Average	-4	-4	-4	-3
Batch 12-06 (MILPRF2104G)	-7	-7	-6	-8
Limits	-14 to 0	-14 to 0	-14 to 0	-14 to 0
Elastomer	P1 A-6-0160-85-ETI			
Volume Change, %				
3 Run Candidate Average	2.71	2.68	3.6	2.3
Limits	0.00 to 8.00	0.00 to 8.00	0.00 to 8.00	0.00 to 8.00
Hardness Change, pts				
3 Run Candidate Average	-2	-2	-3	-2
Limits	-10 to 0	-10 to 0	-10 to 0	-10 to 0
Elastomer	P2 GR-A2256			
Volume Change, %				
3 Run Candidate Average	4.64	4.65	5.14	3.6
Limits	0.00 to 8.00	0.00 to 8.00	0.00 to 8.00	0.00 to 8.00
Hardness Change, pts				
3 Run Candidate Average	-1	-1	0	-4
Limits	-11 to 3	-11 to 3	-11 to 3	-11 to 3
Elastomer	P3 6830			
Volume Change, %				
3 Run Candidate Average	0.32	0.02	0.76	0.10
Limits	0.00 to 4.00	0.00 to 4.00	0.00 to 4.00	0.00 to 4.00
Hardness Change, pts				
3 Run Candidate Average	1	0	1	0
Limits	-8 to 4	-8 to 4	-8 to 4	-8 to 4
Elastomer	F1 7V2127			
Volume Change, %				
3 Run Candidate Average	0.82	0.81	1.2	0.68
Limits	0.00 to 3.00	0.00 to 3.00	0.00 to 3.00	0.00 to 3.00
Hardness Change, pts				
3 Run Candidate Average	0	0	0	-1
Limits	-5 to 4	-5 to 4	-5 to 4	-5 to 4
Elastomer	F2 V150			
Volume Change, %				
3 Run Candidate Average	1.08	1.05	1.42	0.81
Limits	0.00 to 4.00	0.00 to 4.00	0.00 to 4.00	0.00 to 4.00
Hardness Change, pts				
3 Run Candidate Average	0	2	1	0
Limits	-2 to 5	-2 to 5	-2 to 5	-2 to 5
Elastomer	N1 GR-N1386			
Volume Change, %				
3 Run Candidate Average	***-3.01***	***-3.02***	***-2.15***	***-3.25***
Limits	0.00 to 5.00	0.00 to 5.00	0.00 to 5.00	0.00 to 5.00
Hardness Change, pts				
3 Run Candidate Average	7	7	7	1
Limits	-12 to 12	-12 to 12	-12 to 12	-12 to 12

Table 27 shows the results from the paper friction testing. All of the candidates except LO253071 met paper testing frictional requirements. Candidate LO253071 fell short on the minimum midpoint coefficient of friction at the 100 cycles engagement. What this could potentially mean physically, is a greater amount of slip of the friction material during early engagements.

Table 27 – SCPL Candidate Evaluations, Allison C4 Paper Friction

ALLISON C4 PAPER FRICTION TEST

Sponsor Fluid Code: **LO-253071** Test Number: **C2-7-1552**
Lab Fluid Code: **253071** Fric. Plate Batch: **Batch 5**
Completion Date: **07/25/2010** Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.540	0.450	-16.67	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.087	0.114	31.03	F
Static Friction Coeff.	N/A	N/A	0.161	0.125	-22.36	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.173	0.135	-21.97	
0.25 Second Low Speed Coeff.	N/A	N/A	0.163	0.131	-19.63	

ALLISON C4 PAPER FRICTION TEST

Sponsor Fluid Code: **LO-254054** Test Number: **C2-8-1553**
Lab Fluid Code: **254054** Fric. Plate Batch: **Batch 5**
Completion Date: **07/26/2010** Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.480	0.430	-10.42	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.105	0.118	12.38	P
Static Friction Coeff.	N/A	N/A	0.127	0.130	2.36	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.136	0.139	2.21	
0.25 Second Low Speed Coeff.	N/A	N/A	0.131	0.135	3.05	

ALLISON C4 PAPER FRICTION TEST

Sponsor Fluid Code: **LO-250033** Test Number: **C2-5-1550**
Lab Fluid Code: **250033** Fric. Plate Batch: **Batch 5**
Completion Date: Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.470	0.043	-8.51	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.104	0.119	14.42	P
Static Friction Coeff.	N/A	N/A	0.171	0.153	-10.53	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.190	0.168	-11.58	
0.25 Second Low Speed Coeff.	N/A	N/A	0.183	0.163	-10.93	

ALLISON C4 PAPER FRICTION TEST

Sponsor Fluid Code: **LO-251746** Test Number: **C2-6-1551**
Lab Fluid Code: **251746** Fric. Plate Batch: **BATCH 5**
Completion Date: **07/23/2010** Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.470	0.420	-10.64	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.103	0.120	16.50	P
Static Friction Coeff.	N/A	N/A	0.173	0.160	-7.51	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.197	0.173	-12.18	
0.25 Second Low Speed Coeff.	N/A	N/A	0.182	0.165	-9.34	

Table 28 shows the results from the graphite friction testing. Candidates LO254054 was the only oil to fully pass the test. Candidate LO25033 experienced a borderline failure on the minimum midpoint coefficient of friction at the 5,500 cycles engagement (0.086 vs. 0.089 required minimum), but had an acceptable slip time for both loads. Candidates LO253071 and LO251746 did not meet the targets in either slip time or midpoint minimum coefficient of friction. Both candidates performed similarly overall. Each showed a borderline increase in slip time with respect to the maximum allowable for the 5,500 cycles engagement (1,500 cycles engagement OK). For midpoint friction coefficient, each candidate met the minimum at 1,500 cycles engagement but fell below the specification at 5,500 cycles engagement. These results coincide in that the reduced friction coefficient experienced by both candidates at the 5,500 cycles engagement yielded an overall increase of slip time beyond tolerance. It is expected that minor formulation changes could improve this performance.

Full Allison C4 frictional test report data from each candidate test, LO253071, LO254054, LO25033, and LO251746 can be seen in Appendix D1, D2, D3, and D4 respectively. Full FZG evaluation data can be seen in Appendix G.

Table 28 – SCPL Candidate Evaluations, Allison C4 Graphite Friction Testing

ALLISON C4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO253071** | Test Number: **C4-8-1286**
Lab Fluid Code: **253071** | Fric. Plate Batch: **BATCH 44**
Completion Date: **7/22/2010** | Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.79	0.91	15.19	F
0.2 Second Dynamic Coeff.	N/A	N/A	0.084	0.063	-25.000	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.093	0.082	-11.828	F
Static Friction Coeff.	N/A	N/A	0.129	0.112	-13.178	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.154	0.136	-11.688	
0.25 Second Low Speed Coeff.	N/A	N/A	0.130	0.123	-5.385	

ALLISON C4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO254054** | Test Number: **C4-9-1287**
Lab Fluid Code: **254054** | Fric. Plate Batch: **Batch 44**
Completion Date: **7/23/2010** | Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.68	0.71	4.41	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.109	0.099	-9.174	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.110	0.107	-2.727	P
Static Friction Coeff.	N/A	N/A	0.124	0.125	0.806	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.139	0.139	0.000	
0.25 Second Low Speed Coeff.	N/A	N/A	0.133	0.128	-3.759	

ALLISON C4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO250033** | Test Number: **C4-6-1284**
Lab Fluid Code: **250033** | Fric. Plate Batch: **Batch 44**
Completion Date: **7/20/2010** | Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.80	0.89	11.25	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.078	0.060	-23.077	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.093	0.086	-7.527	F
Static Friction Coeff.	N/A	N/A	0.133	0.125	-6.015	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.151	0.156	3.311	
0.25 Second Low Speed Coeff.	N/A	N/A	0.143	0.138	-3.497	

ALLISON C4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO251746** | Test Number: **C4-7-1285**
Lab Fluid Code: **251746** | Fric. Plate Batch: **Batch 44**
Completion Date: **7/21/2010** | Steel Plate Batch: **10/9/2008**

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.81	0.90	11.11	F
0.2 Second Dynamic Coeff.	N/A	N/A	0.072	0.048	-33.333	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.090	0.084	-6.667	F
Static Friction Coeff.	N/A	N/A	0.142	0.136	-4.225	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.160	0.153	-4.375	
0.25 Second Low Speed Coeff.	N/A	N/A	0.149	0.142	-4.698	

3.3.2 Caterpillar TO-4 Testing

Similar to the Allison C4 transmission compatibility tests, Caterpillar TO-4 standardized tests were completed on each candidate to assess potential performance in Caterpillar transmission applications. The Caterpillar TO-4 testing matrix for the SCPL candidates included frictional testing on sintered bronze and wheel brake paper, as well as FZG scuffing and wear testing.

Table 29 shows the FZG scuffing and wear results for each SCPL candidate fluid. For FZG scuffing, each of the candidates provided adequate performance and protection. For SAE 10 and 30 grade oils, the candidate oil must be able to pass the number 8 load stage (SAE 40 and 50 grade oils must pass load stage 10), in which each candidate succeeded. Testing was continued until failure was observed to determine the limits of the oil. A total of 12 load stages are defined for testing. To determine FZG wear, gear weight loss across three separate runs is used to test the candidate oils overall gear wear protection. For lubricants to meet Caterpillar FZG approval, the CAT TO-4 method specifies that a total average weight loss over three runs is below 100mg, and no single run can be over 150mg. Each candidate successfully passed Caterpillar specifications for the FZG wear testing.

Table 29 – SCPL Candidate Evaluations, FZG Scuffing and Wear

		LO253071 (LZ OEA-20)	**LO254054 (LZ STOU)**
Description	**Method**	**Results**	**Results**
FZG Scuffing	ASTM D5182-97	Pass (Fail Load Stage 12)*	Pass (Fail Load Stage 9)*
FZG Wear	ASTM D4998	Pass*	Pass*
		LO250033 (INF 0W-30)	**LO251746 (INF 0W-20)**
		Results	**Results**
FZG Scuffing	ASTM D5182-97	Pass (Fail Load Stage 12)*	Pass (Fail Load Stage 12)*
FZG Wear	ASTM D4998	Pass*	Pass*
		**Compared to CAT-TO-4 Fluid Specifications*	

Table 30 shows a summary of the CAT TO-4 frictional testing including wheel brake paper, and sintered bronze. Both candidates LO253071 and LO25033 passed the Sequence 1220 (sintered bronze) test while candidate LO254054 failed on the dynamic testing phase. Candidate LO251746 failed both dynamic and static phases. For candidate LO254054, the overall dynamic coefficients were borderline below the minimum limits, but remained consistent through all the tested cycles. This indicates that, although a technical failure, the oil would not be expected to cause catastrophic problems within a transmission. For candidate LO251746, the dynamic coefficients of friction were slightly over the upper limit, but did not show any negative inconsistencies in the coefficient traces that would indicate absolute problems. (Full coefficient of friction traces can be seen in each respective appendix).

For Sequence 1222 (wheel brake paper), none of the candidates tested fully passed. All of the candidates except LO251746 experienced only borderline line failures which would not be considered extreme. For candidate LO251746, the measured dynamic coefficients were considerably lower than limits generated by the baseline fluid, and static coefficients were only borderline low like the remaining candidates. Further modifications would need to be made to this fluid to successfully pass this test. (Full coefficient of friction traces can be seen in each respective appendix).

Lastly, for the friction retention testing, which also used sintered bronze disks, all candidates passed within test limits.

It is expected that all of the borderline failures for the SCPL candidates could be corrected with slight formulation changes. None of the SCPL candidates exhibited behaviors that would be considered catastrophic if used in transmissions, but room for improvement remains for the SCPL oils in regards to Caterpillar TO-4 friction testing. Full Caterpillar TO-4 test report data from each candidate test, LO253071, LO254054, LO25033, and LO251746 can be seen in Appendix E1, E2, E3, and E4 respectively.

Table 30 – SCPL Candidate Evaluations, Caterpillar TO-4 Friction Testing

CAT TO-4	LO253071 (LZ OEA-20)	LO254054 (LZ STOU)	LO250033 (INF 0W-30)	LO251746 (INF 0W-20)
Sequence 1220				
Dynamic Coef vs Cycle	Pass	Fail	Pass	Fail
Dynamic Coef vs Load	Pass	Fail	Pass	Fail
Dynamic Coef vs Speed	Pass	Fail	Pass	Fail
Energy Limit	Pass	Pass	Pass	Pass
Static Coef vs Load	Pass	Pass	Pass	Fail
Static Coef vs Speed	Pass	Pass	Pass	Fail
Energy Limit	Pass	Pass	Pass	Pass
Total Wear	0.039	0.08	0.014	0.039
Sequence 1222				
Dynamic Coef vs Cycle	Fail	Pass	Fail	Fail
Dynamic Coef vs Load	Fail	Pass	Fail	Fail
Dynamic Coef vs Speed	Fail	Pass	Pass	Fail
Energy Limit	Pass	Pass	Pass	Pass
Static Coef vs Load	Fail	Fail	Pass	Fail
Static Coef vs Speed	Pass	Fail	Pass	Fail
Energy Limit	Pass	Pass	Pass	Pass
Total Wear	0.03	0.039	0.028	0.007
Friction Retention				
	Pass	Pass	Pass	Pass

3.3.3 John Deere JDQ-96 Wet Brake Testing

John Deere JDQ-96 testing assess a lubricants interactions with a submerged wet braking system. For SCPL evaluations, an abbreviated 1000 cycle test was run to get an indication of overall compatibility. Two primary parameters of interest are the relative capacity, and overall torque variation. The relative capacity is a measure of the overall torque capacity of the system with the lubricant being tested. In Table 31, each of the SCPL candidates provided adequate torque capacity compared to the reference fluid baseline. The second parameter of interest, torque variation, is a quantification of the overall noise of the system, and is a measure of the difference in torque variation from the peak and valley of a torque trace at the completion of 1000 cycles. The overall torque variation for all of the SCPL candidates was larger than that of the reference fluid, which has been noted in previous testing as being typical of engine oils in this application. This explains each fluid being noted as creating high levels of brake noise. Other than a higher level of audible noise, this increase should pose no adverse effects on overall function and usability of the system. From discussions on industry testing, the magnitude of torque variation has been found to be highly hardware dependant, even from hardware supplied from a single source.

Full JDQ-96 test report data from each candidate test, LO253071, LO254054, LO25033, and LO251746 can be seen in Appendix F1, F2, F3, and F4 respectively.

Table 31 – SCPL Candidate Evaluations, JDQ-96 Wet Brake Compatibility

John Deere JDQ-96 **Performed using 1400 Series Axle**				
Test Number	10827	10739	10979	10547
Oil Code	LO250033	LO251746	LO253071	LO254054
EOT Date	7/30/2010	7/31/2010	8/2/2010	8/3/2010
	Current Reference Baseline Average (N*m)			
Relative Capacity @ 1,000 Cycles	342,372			
Torque Variation @ 1,000 Cycles	93,746			
	Results From Test Candidate			
Relative Capacity @ 1,000 Cycles	403,778	398,534	360,738	386,450
Torque Variation @ 1,000 Cycles	255,990	253,990	164,190	192,440
**Notes	This oil created high levels of brake noise.	This oil created high levels of brake noise.	This oil created high levels of brake noise.	This oil created high levels of brake noise.

3.4 ENGINE FUEL CONSUMPTION IMPROVEMENT

To quantify fuel consumption improvements from the use of the SCPL candidates, it was desired to set up a “standardized” test to measure the fuel consumption of a baseline oil compared to each SCPL candidate. The following sections summarize the efforts to configure a test stand and develop a test cycle, outlines procedures used during fuel consumption testing, and discusses results seen during the SCPL evaluations.

3.4.1 Stand Configuration and Cycle Development

Fuel consumption evaluations were conducted on a test stand configured for the GEP 6.5L(T) engine, similar in many ways to the stand used for endurance evaluations. Variations between the two stands included oil system heat exchanger layout and the inclusion of an inlet air cooler for temperature control. As is discussed in Appendix H, field data from a HMMWV was used to create a series of 26 operating modes. After determining which modes had the highest repeatability when conducted in the laboratory setting, a 14-mode cycle was derived which allows the engine to stabilize at each point for 15 minutes. Power output and fuel flow rate, measured by a coriolis mass-flow meter, are used to calculate the engine break-specific fuel consumption (BSFC) for that mode. After completing all 14 modes, each BSFC value was weighted based upon total fuel flow rate for the mode to form a cycle BSFC result. For each lubricant evaluation, the cycle was repeated seven times for statistical purposes.

3.4.2 Fuel Consumption Test Procedure

Prior to testing each candidate oil, a baseline SAE 40 was run to account for engine drift over time. Oil was changed in the engine using a double flush method along with filter change. Once fluid levels were set, the engine was started and idled for 60 seconds to stabilize operation and check for system leaks. Next, a 1500 rpm, half throttle warm-up brought up engine coolant and oil temperatures. Throughout testing, inlet air was maintained at 75°F, while fuel temperature was controlled to 95°F. Throughout all testing, the fuel source was identical to the that used in SCPL endurance testing (Appendix I). Following warm-up, the engine was brought to rated conditions, 3400 rpm and full throttle, to set inlet and exhaust restrictions. The engine was then controlled to 1100 rpm and 60 lbft for 30 minutes to stabilize oil temperature before continuing with the 14-mode cycle shown in Table 32.

Table 32 – GEP 6.5L(T) Fuel Consumption Test Points

Point	RPM	Torque, lbf*ft	Power, hp	Oil Sump, ˚F	Intake Air, ˚F	Fuel Inlet, ˚F
1	1100	59.7	12.5	165	75	95
2	2100	59.7	23.9	180		
3	1100	99.6	20.9			
4	1100	179.2	37.5			
5	1600	99.6	30.3	195		
6	2100	139.4	55.7			
7	2600	99.6	49.3	215		
8	2100	179.2	71.7			
9	3100	99.6	58.8			
10	2600	139.4	69.0			
11	3100	139.4	82.3	245		
12	2600	179.2	88.7			
13	2400	302.4	138.2			
14	2800	250.8	133.7			

At the completion of mode 14, the engine would return to the 30 minute stabilization step for another cycle. This continued until all seven cycles were completed. In the event of a shut-down, the cycle was restarted from the temperature stabilization step.

For the evaluation of drain lubricants from endurance testing, a simple drain and fill method was used following the testing of fresh oil to reduce the used fluid that would be lost during the oil change process.

3.4.3 Candidate Results

Results from the candidate SCPL lubricants are shown in Table 33 for both fresh oil and EOT drains where available.

Table 33 – GEP 6.5L(T) Fuel Consumption Test Matrix & Results

Lubricating Oil	% Improvement Fresh	% Improvement EOT
MIL-PRF-2104G SAE 15W-40 LO246362	0.83	N/A
MIL-PRF-2104H SAE 15W-40 LO257264	0.86	N/A
MIL-PRF-46167 OEA-30 (Batch A) LO241026	2.27	1.26
MIL-PRF-46167 OEA-30 (Batch B) LO247699	2.38	N/A
SCPL Candidate LO253071	2.51	2.01
SCPL Candidate LO251764	2.41	1.83
SCPL Candidate LO250033	2.00	0.37
Commercial API-CJ4 SAE15W-40 LO257421	0.27	-2.14
Commercial API-CJ4 SAE5W-40	0.36	N/A
SCPL Candidate LO254054	1.54	N/A

The use of low viscosity oils showed a measurable improvement over both the test baseline and current MIL-PRF-2104 oils. Even at end-of-life conditions, which were typically pushed past normal oil change intervals, the lubricants were shown to offer fuel consumption benefits. The difference in improvement noted between two batches of MIL-PRF-46167 was not statistically significant, nor was the shift between MIL-PRF-2104 G and H.

4.0 CONCLUSIONS

From testing completed, the industry supplied SCPL candidates provided promising results into the development of the SCPL. Although not all of the candidates met desired performance levels, the selected candidates received should provide an excellent baseline to further refine and develop the lubricants to meet SCPL performance requirements.

The GEP 6.5L(T) high temperature oil endurance test developed to evaluate the SCPL candidates provided excellent comparison between baseline lubricants and candidates when used in high temperature (i.e. severe) engine applications. High levels of consistency were able to be achieved between each test run which allowed for good comparisons across multiple tests to analyze lubricant performance. The de facto SCPL, MIL-PRF-46167D OEA-30, was found to provide adequate performance through 140 hours of high temperature testing in the 6.5L(T) engine. This was an improvement over results found during MIL-PRF-2104G testing, but was closely comparable to the MIL-PRF-2104H revision, which showed a much improved oxidation resistance and overall stability. Two of the supplied SCPL candidates, LO25033 and LO251746, were also found to have an increased resistance to oxidation and degradation during testing, and exceeded all of the baseline results acquired during OEA-30 testing by successfully operating for 168 hours despite the conservative early test termination. From the post test metrology results, all of the tested SCPL candidates provided adequate engine protection when compared to tested MIL specification and commercial SAE 15W-40 engine oils, despite their lowered viscosity. Apart from an indication of increased ring pack wear, all of the lower viscosity SCPL candidates provided equivalent or improved wear protection, and successfully controlled internal deposits.

Transmission testing completed on the candidates confirmed the possibilities of using the SCPL in powershift transmission applications. Although further modifications in formulation will be required, none of the SCPL candidates exhibited a catastrophic incompatibility with typical transmission components they would be expected to come into contact with. Allison C4 seal compatibility testing completed showed all of the SCPL candidates compatible, aside from the exception of nitrile, with common elastomers used in dynamic and static seal construction. Frictional testing in the Allison C4 and Caterpillar TO-4 tests showed overall positive results, but as mentioned, highlighted areas that need improvement before final SCPL implementation. Gear

protection was shown during from FZG scuffing and wear testing. Wet brake applications showed expected results in the John Deere JDQ-96 testing.

Lastly, fuel consumption improvements were found to be positive, and helped show that through the use of low viscosity lubricants, potential savings for the military could be realized. Results from SCPL testing show anywhere from a 1.5 to 2.5% improvement in fuel consumption when compared to the baseline straight SAE 40 grade reference oil. This translates into an approximate 0.5 to 1.5% improvement over standard military diesel engine oils. These savings, combined with of extended drain intervals, all help in making the SCPL lubricant a desirable alternative to currently used products.

5.0 RECOMMENDATIONS

It is the recommendation of TFLRF staff that two of the tested candidates, LO253071 and LO251746, be resubmitted to their respective supplier for further revisions. LO253071 was chosen primarily due to its close ties to the currently approved MIL-PRF-46167D arctic engine oil. Although in engine testing this SCPL candidate did not meet the same overall test duration as the OEA-30, its overall chemical and physical properties and close ties to currently approved products make it a desirable contender. Further work will be required to improve its transmission compatibility, and any candidate revision should also address the indication of increased cam shaft wear seen during preliminary testing. LO251746 was chosen primarily because of its excellent performance as seen during the 6.5L(T) high temperature endurance testing. This candidate, like LO253071, had some shortcomings in the transmission testing section, but appears to require only minor formulation changes to meet desired performance levels in each areas of interest. Results gathered to date for both candidates provide a clear picture of current performance, and highlight areas that require further improvement. Main areas of emphasis for reformulation efforts need to be focused on:

- Improved oxidation stability
- Improved frictional response in standardized transmission testing

As one of the most primary goals of the SCPL, improved oxidation stability and overall oil degradation control in severe applications will ultimately lead to extended drain benefits and increased engine protection. These two aspects are key to the implementation of the SCPL. In addition, changes to each formulation to improve frictional response in transmission applications will be required so that the SCPL can serve as a drop in replacement for the currently utilized MIL-PRF-2104H products.

In addition to the items listed above, long term considerations for the SCPL program should include:

- Two–cycle diesel engine compatibility testing
- Investigation of ring pack wear changes due to lowered viscosities
- Conduct multiple field demonstrations at US Army posts consisting of cold, moderate, and high temperature climate conditions.

6.0 REFERENCES

1. Warden, R.W., Frame, E.A., Brandt, A. C., *"SAE J1321 Testing Using M1083A1 FMTVS"*, Interim Report TFLRF No. 404, ADA 528430, March 2010.

2. Warden, R.W, et. al. "Fuel Efficiency Effects of Lubricants in Military Vehicles," SAE Technical Paper 2010-01-280, 2010

3. Brandt, A.C., Frame, E.A., Alvarez, R.A., *"Feasibility of using Full Synthetic Low Viscosity Engine Oil at High Ambient Temperatures in U.S. Army Engines"*, Interim Report TFLRF No. 415, ADA560574, June 2011.

4. Brandt, A.C., et. al. "Feasibility of Using Full Synthetic Low Viscosity Engine Oil at High Ambient Temperatures in Military Vehicles," SAE Technical Paper 2010-01-2176, 2010

5. Brandt, A.C., Frame, E.A., "Transmission Bench Testing for Single Common Powertrain Lubricant Candidates", Draft Interim Report TFLRF No. 417, January 2012.

6. Development of Military Fuel/Lubricant/Engine Compatibility Test, CRC Report 406, January 1967.

APPENDIX A1. – MIL-PRF-46167 OEA, REPEATABILITY RUN 1 OF 3

REPEATABILITY EVALUATION 1 OF 3
MIL-PRF-46167D
OEA-30 ARCTIC OIL

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-241026
Arctic Oil – OEA30
Test Fuel: Jet-A w/DCI-4A
Test Number: LO241026-65T1-W-210
Start of Test Date: March 29, 2010
End of Test Date: April 09, 2010
Test Duration: 140 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the statistical repeatability of MIL-PRF-46167D OEA-30 arctic oil when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

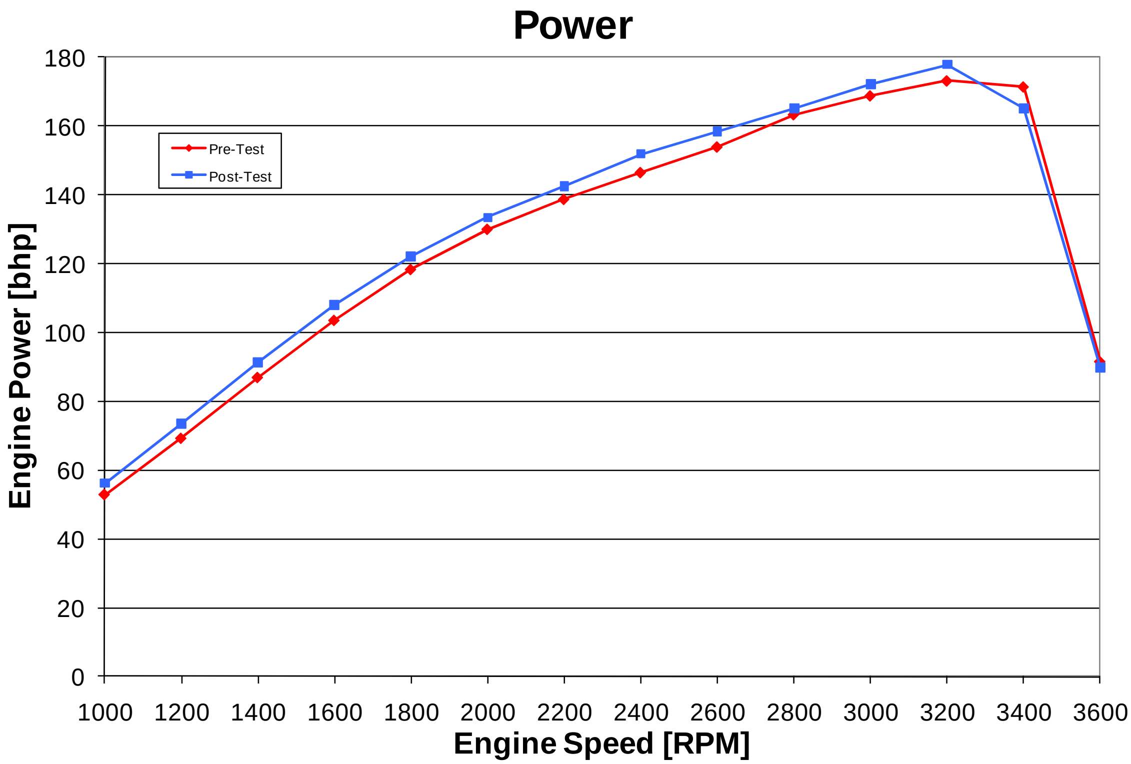
Engine Operating Conditions Summary

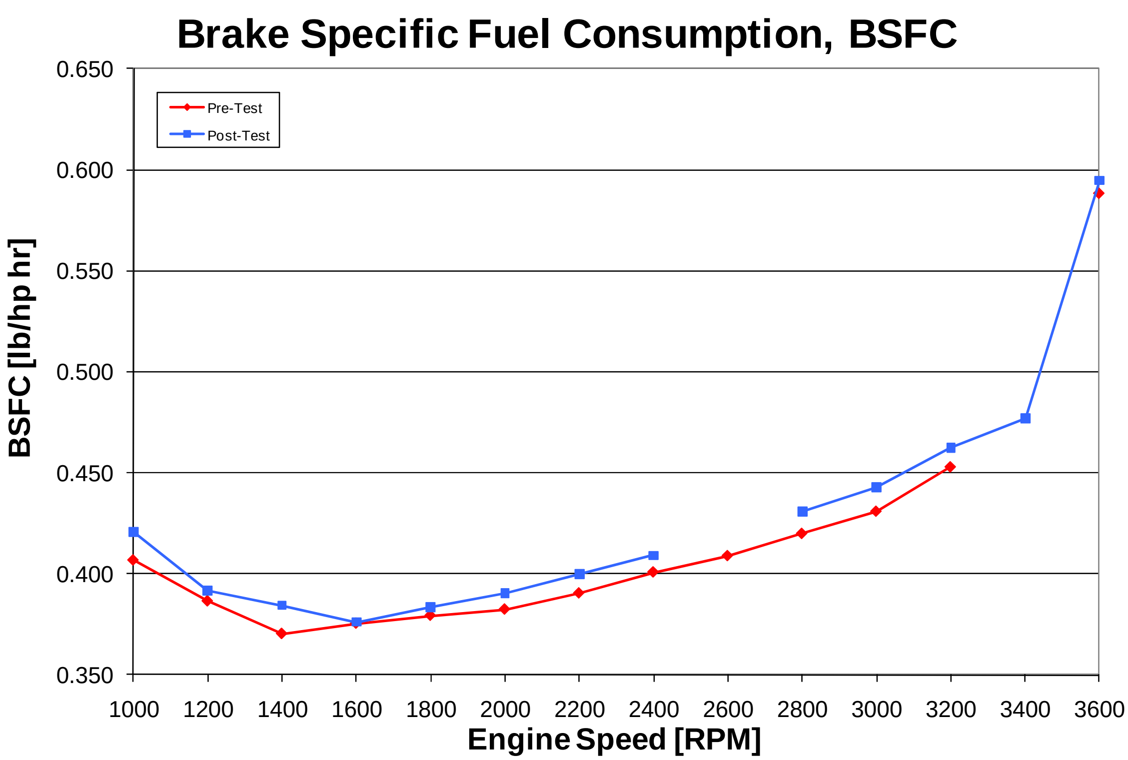
Below is a summary of the engine operating conditions over the test duration. Testing was stopped at 140hrs due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.01	0.79	900.16	1.79
Torque*	ft*lb	255.49	3.39	27.21	8.33
Fuel Flow	lb/hr	77.76	9.18	5.67	0.48
Power*	bhp	165.40	2.19	4.66	1.42
BSFC*	lb/bhp*hr	0.470	0.056	1.269	0.203
Temperatures:					
Coolant In	°F	191.68	2.58	92.76	2.04
Coolant Out	°F	204.86	2.45	99.93	1.86
Oil Sump	°F	260.01	0.62	125.00	2.58
Fuel In	°F	95.07	1.84	94.98	0.36
Intake Air	°F	91.05	7.01	83.50	5.65
Cylinder 1 Exhaust	°F	1102.53	13.18	166.09	12.21
Cylinder 2 Exhaust	°F	1085.62	17.85	165.68	11.17
Cylinder 3 Exhaust	°F	1188.99	15.62	174.04	12.92
Cylinder 4 Exhaust	°F	1094.77	12.55	174.67	10.58
Cylinder 5 Exhaust	°F	1145.91	14.06	182.94	79.80
Cylinder 6 Exhaust	°F	1127.73	15.35	175.68	10.81
Cylinder 7 Exhaust	°F	1092.92	18.03	165.99	11.39
Cylinder 8 Exhaust	°F	1172.12	16.07	182.96	10.13
Pressures:					
Oil Galley	psi	39.93	0.53	38.34	2.04
Ambient Pressure	psiA	14.21	0.07	14.20	0.07
Boost Pressure	psi	4.54	0.09	-0.11	0.05

*Non-Corrected Values

Engine Performance Curves



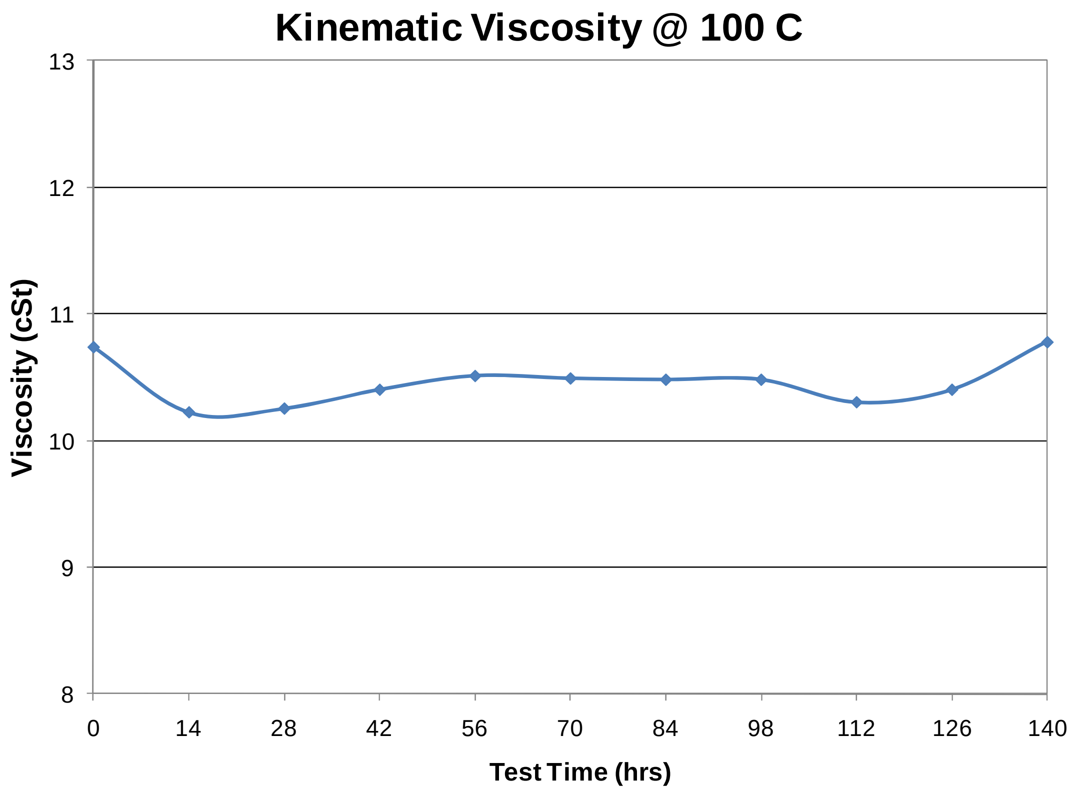


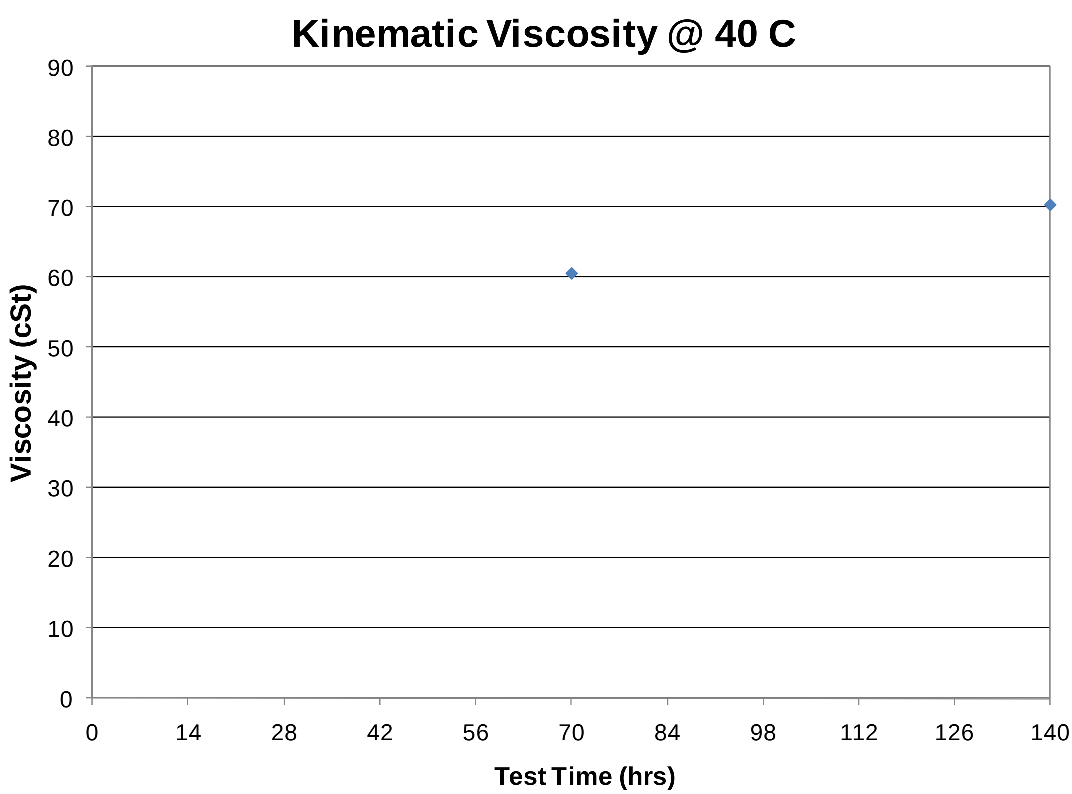
*Note – Breaks in BSFC plot due to invalid values for engine fuel flow during powercurve.

Engine Oil Analysis

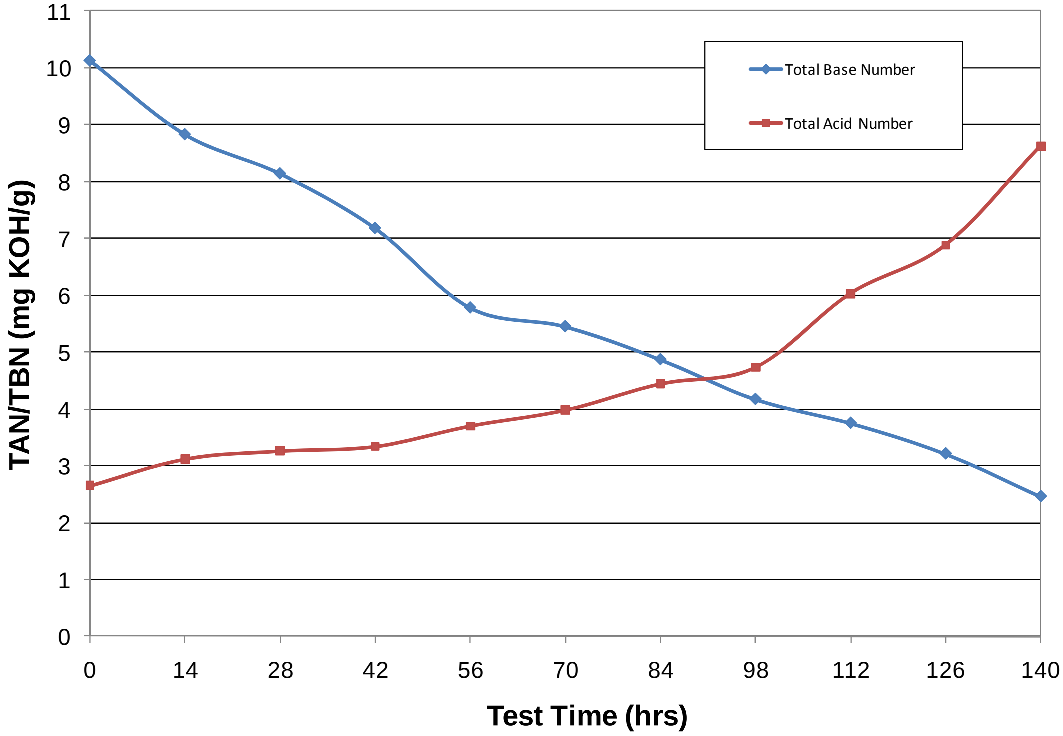
Property	ASTM Test	Test Hours										
		0	14	28	42	56	70	84	98	112	126	140
Density	D4052	0.849	0.851	0.854	0.856	0.858	0.860	0.863	0.865	0.869	0.874	0.883
Viscosity @ 100°C (cSt)	D445	10.7	10.2	10.3	10.4	10.5	10.5	10.5	10.5	10.3	10.4	10.8
Viscosity @ 40°C (cSt)	D445						60.6					70.3
Viscosity Index	D2270						163					142
Total Base Number (mg KOH/g)	D4739	10.1	8.8	8.1	7.2	5.8	5.5	4.9	4.2	3.8	3.2	2.5
Total Acid Number (mg KOH/g)	D664	2.7	3.1	3.3	3.3	3.7	4.0	4.4	4.7	6.0	6.9	8.6
Oxidation (Abs./cm)	E168 FTNG	0.0	3.1	8.3	14.1	19.4	24.1	30.1	36.9	47.3	65.8	102.7
Nitration (Abs./cm)	E168 FTNG	0.0	5.7	6.9	6.6	7.5	10.8	15.3	20.6	30.0	41.6	53.2
Soot (m%)	Soot TGA	0.1	0.3	0.4	0.5	0.8	0.8	0.9	1.1	1.3	1.4	1.8
Wear Metals (ppm)	D5185											
Al		1	2	2	2	2	3	3	3	3	3	4
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	11	<1	<1
B		<1	<1	2	3	2	2	3	3	3	3	6
Ca		3373	3537	3855	3941	4142	4455	4550	4662	4680	4642	4711
Cr		<1	1	2	3	4	5	5	6	7	7	8
Cu		<1	16	23	28	33	36	38	39	43	54	124
Fe		2	34	66	93	120	149	178	207	239	273	365
Pb		<1	5	7	9	11	14	18	24	35	65	194
Mg		10	12	14	16	16	17	18	18	19	19	21
Mn		<1	<1	2	2	2	3	3	4	4	4	6
Mo		<1	5	9	12	14	16	18	19	20	21	22
Ni		<1	1	2	3	3	4	4	5	5	6	6
P		1296	1219	1220	1189	1243	1318	1330	1357	1390	1334	1362
Si		5	11	17	17	16	16	20	20	19	19	20
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		<5	<5	5	<5	6	8	9	10	8	7	5
Sn		<1	3	5	6	8	9	10	11	11	12	14
Zn		1469	1459	1521	1558	1606	1675	1712	1759	1812	1831	1854
K		<5	<5	<5	<5	6	5	<5	<5	5	<5	<5
Sr		1	1	1	1	2	1	1	1	2	2	1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	1	2	4

Engine Oil Analysis Trends

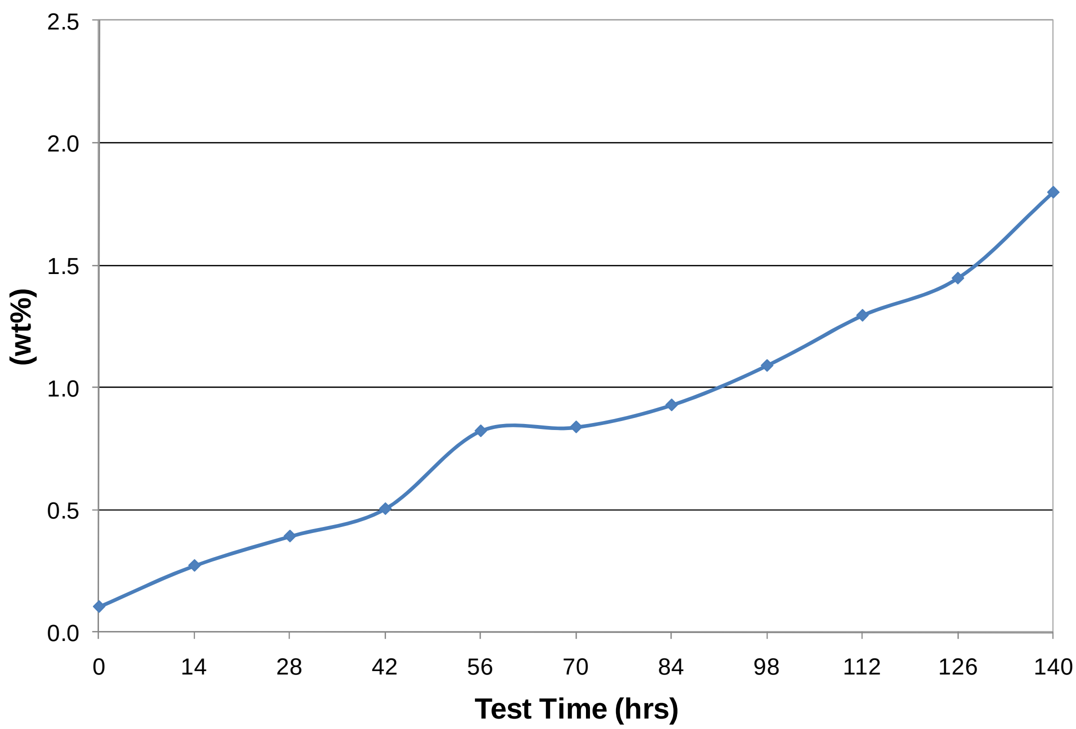


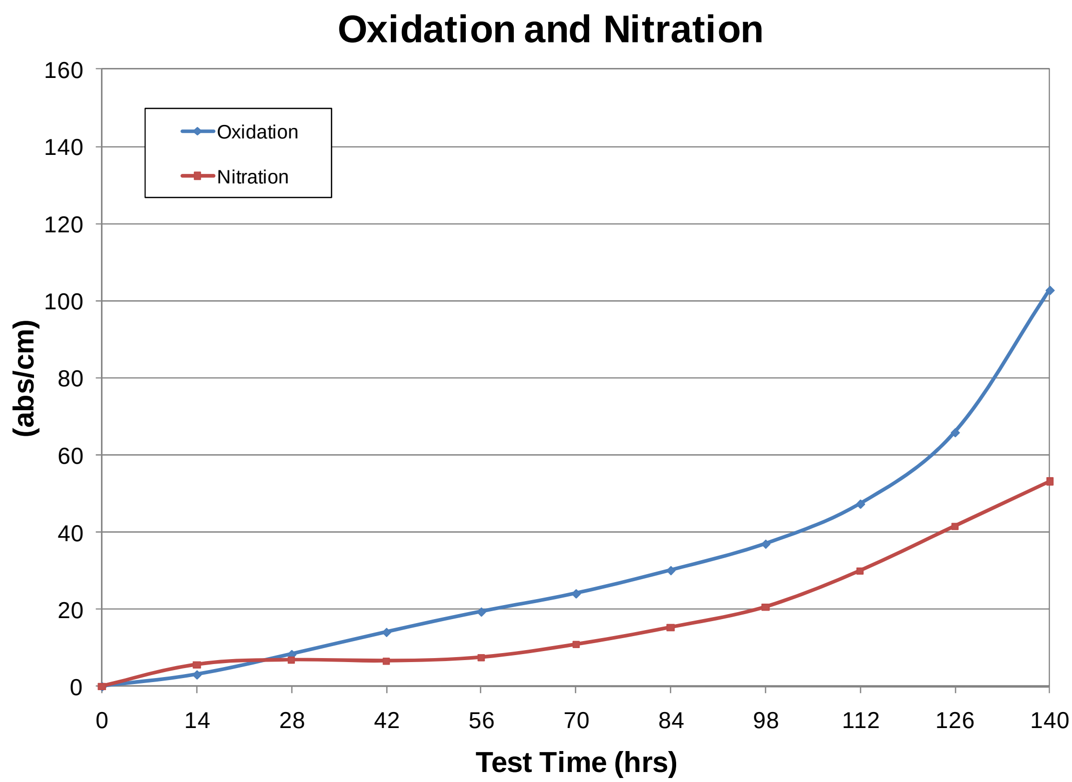


Total Acid and Base Numbers

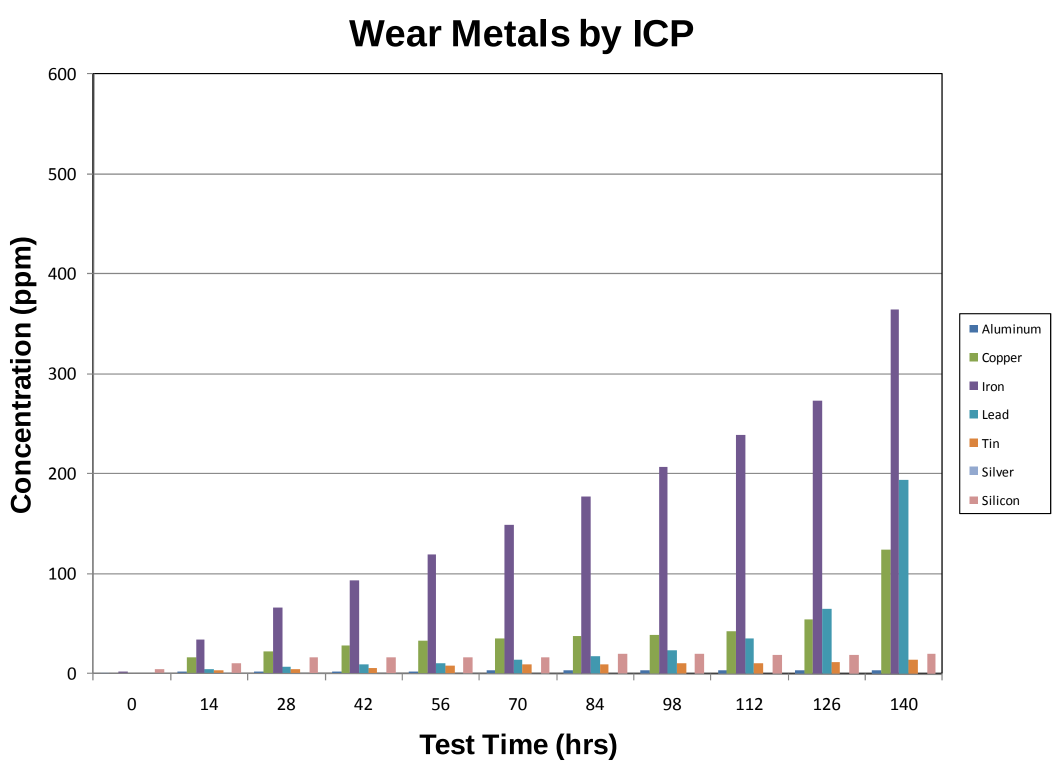


Soot





Oxidation and Nitration
160
140
120
100
80
60
40
20
0
(abs/cm)
Oxidation
Nitration
0
14
28
42
56
70
84
98
112
126
140
Test Time (hrs)



Wear Metals by ICP
600
500
400
300
200
100
0
Concentration (ppm)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon
0
14
28
42
56
70
84
98
112
126
140
Test Time (hrs)

Oil Consumption Data

Average oil consumption per test hour was 0.061 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14-hr	0	0.23	*-0.23*	*-0.23*
28-hr	0.78	0.26	0.52	0.29
42-hr	1.35	0.24	1.11	1.4
56-hr	1.81	0.22	1.59	2.99
70-hr	1.34	0.22	1.12	4.11
84-hr	1.5	0.26	1.24	5.35
98-hr	1.3	0.25	1.05	6.4
112-hr	1.42	0.26	1.16	7.56
126-hr	1.35	0.25	1.1	8.66
140-hr	1.44	0.25	1.19	9.85
	Initial Fill	13.97	**Total Additions**	12.29
	EOT Drain	15.28	**Total Samples**	2.44

(Initial Fill + Additions)	26.26
(EOT Drain + Samples)	17.72
Total Oil Consumption	8.54

Post Test Engine Ratings

Ratings	Clyinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	No	No	No	No	No	No	No	No	--
Ring No.2	No	No	No	No	No	No	No	No	--
Ring No.3	No	No	No	No	No	No	No	No	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	65.00	92.00	49.25	50.25	37.25	60.75	73.25	99.00	65.84
No.2 Groove	10.00	0.00	3.75	1.50	4.25	0.00	0.25	5.50	3.16
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	45.25	61.25	46.25	57.50	42.50	70.00	56.50	46.75	53.25
No.2 Land	17.00	7.25	19.00	8.25	7.50	1.00	8.25	16.00	10.53
No.3 Land	1.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.25
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00	1.25
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	1.58	3.90	3.34	2.85	2.46	2.37	3.93	2.92	2.92
No.3 Groove	1.50	1.74	1.20	1.80	1.52	1.95	2.21	2.44	1.80
No.1 Land	0.00	0.01	0.18	0.17	0.45	0.00	0.00	0.00	0.10
No.2 Land	1.06	3.12	1.13	1.98	1.66	2.58	2.83	1.00	1.92
No.3 Land	1.72	2.33	1.86	1.77	1.97	2.10	1.50	2.20	1.93
Upper Skirt	0.55	0.77	0.77	0.66	0.52	0.53	0.39	0.90	0.64
Under Crown	4.10	3.21	3.70	2.30	2.22	3.52	4.00	2.30	3.17
Front Pin Bore	1.13	1.24	1.24	1.37	1.37	1.24	1.36	1.30	1.28
Rear Pin Bore	1.00	1.24	1.24	1.55	1.37	1.24	1.36	1.30	1.29
Total, Demerits	150.89	178.06	132.91	131.95	105.04	147.28	155.83	192.61	149.32
Miscellanous									
Top Groove Fill, %	61	96	49	53	24	54	69	99	63.13
Intermediate Groove Fill, %	4	0	1	0	1	0	0	2	1.00
Top Land Heavy Carbon, %	27	49	29	44	25	60	42	29	38.13
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0	0	0.00
Valve Tulip Deposits, Merits									
Exahust	9.0	9.0	9.0	9.0	8.9	9.0	9.1	9.1	9.01
Intake	6.5	7.1	7.7	6.5	7.8	6.5	7.5	7.7	7.16

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0545	4.0552	4.0547	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0000	0.0006	0.0003	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0002	0.0005	0.0003	
Piston Skirt Diameter	4.0489	4.0491	4.0490	
Piston Skirt to Cylinder Bore Clearance	0.0054	0.0062	0.0057	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.017	0.022	0.020	
Second Ring	0.036	0.039	0.038	
Oil Control Ring	0.016	0.020	0.018	
Ring To Groove Clearance				
Second Ring	0.0180	0.0200	0.0185	0.0015"-0.003"
Bearing Clearances				
Connecting Rod to Journal	0.0020	0.0025	0.0023	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0030	0.0022	0.001"-0.005"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0548	4.0545		0.0003
	Middle	4.0546	4.0541	4.0546	0.0005
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0003	0.0004		
2	Top	4.0548	4.0545		0.0003
	Middle	4.0546	4.0542	4.0545	0.0004
	Bottom	4.0544	4.0543		0.0001
	Taper	0.0004	0.0003		
3	Top	4.0549	4.0543		0.0006
	Middle	4.0546	4.0542	4.0546	0.0004
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0004	0.0002		
4	Top	4.0549	4.0544		0.0005
	Middle	4.0546	4.0541	4.0545	0.0005
	Bottom	4.0544	4.0544		0.0000
	Taper	0.0005	0.0003		
5	Top	4.0551	4.0546		0.0005
	Middle	4.0549	4.0544	4.0549	0.0005
	Bottom	4.0548	4.0547		0.0001
	Taper	0.0003	0.0003		
6	Top	4.0552	4.0546		0.0006
	Middle	4.0547	4.0544	4.0547	0.0003
	Bottom	4.0547	4.0546		0.0001
	Taper	0.0005	0.0002		
7	Top	4.0554	4.0551		0.0003
	Middle	4.0553	4.0548	4.0552	0.0005
	Bottom	4.0551	4.0550		0.0001
	Taper	0.0003	0.0003		
8	Top	4.0554	4.0551		0.0003
	Middle	4.0551	4.0549	4.0551	0.0002
	Bottom	4.0550	4.0552		0.0002
	Taper	0.0004	0.0003		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0550	4.0557		0.0007
	Middle	4.0553	4.0563	4.0554	0.0010
	Bottom	4.0554	4.0558		0.0004
	Taper	0.0004	0.0006		
2	Top	4.0550	4.0558		0.0008
	Middle	4.0552	4.0562	4.0553	0.0010
	Bottom	4.0554	4.0558		0.0004
	Taper	0.0004	0.0004		
3	Top	4.0550	4.0560		0.0010
	Middle	4.0551	4.0563	4.0553	0.0012
	Bottom	4.0554	4.0558		0.0004
	Taper	0.0004	0.0005		
4	Top	4.0550	4.0559		0.0009
	Middle	4.0552	4.0563	4.0553	0.0011
	Bottom	4.0554	4.0558		0.0004
	Taper	0.0004	0.0005		
5	Top	4.0550	4.0558		0.0008
	Middle	4.0551	4.0561	4.0552	0.0010
	Bottom	4.0552	4.0555		0.0003
	Taper	0.0002	0.0006		
6	Top	4.0549	4.0558		0.0009
	Middle	4.0550	4.0562	4.0551	0.0012
	Bottom	4.0552	4.0555		0.0003
	Taper	0.0003	0.0007		
7	Top	4.0550	4.0553		0.0003
	Middle	4.0551	4.0557	4.0552	0.0006
	Bottom	4.0552	4.0554		0.0002
	Taper	0.0002	0.0004		
8	Top	4.0550	4.0553		0.0003
	Middle	4.0550	4.0559	4.0551	0.0009
	Bottom	4.0552	4.0553		0.0001
	Taper	0.0002	0.0006		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0002	0.0012	
	Middle	0.0007	0.0022	0.0008
	Bottom	0.0009	0.0014	
2	Top	0.0002	0.0013	
	Middle	0.0006	0.0020	0.0008
	Bottom	0.0010	0.0015	
3	Top	0.0001	0.0017	
	Middle	0.0005	0.0021	0.0007
	Bottom	0.0009	0.0014	
4	Top	0.0001	0.0015	
	Middle	0.0006	0.0022	0.0008
	Bottom	0.0010	0.0014	
5	Top	0.0001	0.0012	
	Middle	0.0002	0.0017	0.0003
	Bottom	0.0004	0.0008	
6	Top	0.0003	0.0012	
	Middle	0.0003	0.0018	0.0004
	Bottom	0.0005	0.0009	
7	Top	0.0004	0.0002	
	Middle	0.0002	0.0009	0.0001
	Bottom	0.0001	0.0004	
8	Top	0.0004	0.0002	
	Middle	0.0001	0.0010	0.0002
	Bottom	0.0002	0.0001	
Avgerage All Cylinders	Top	0.0002	0.0011	
	Middle	0.0004	0.0017	
	Bottom	0.0006	0.0010	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	U/A	0.3428	U/A	U/A	0.3732	U/A
2	U/A	0.3428	U/A	U/A	0.3739	U/A
3	U/A	0.3425	U/A	U/A	0.3739	U/A
4	U/A	0.3428	U/A	U/A	0.3739	U/A
5	U/A	0.3427	U/A	U/A	0.3732	U/A
6	U/A	0.3428	U/A	U/A	0.3739	U/A
7	U/A	0.3428	U/A	U/A	0.3732	U/A
8	U/A	0.3428	U/A	U/A	0.3739	U/A

Maximum	0.3428		Maximum	0.3739
Average	0.3428		Average	0.3736

Valve Stem Measurement Changes, inches

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	U/A	0.3412	U/A	U/A	0.3711	U/A
2	U/A	0.3412	U/A	U/A	0.3709	U/A
3	U/A	0.3411	U/A	U/A	0.3710	U/A
4	U/A	0.3410	U/A	U/A	0.3709	U/A
5	U/A	0.3411	U/A	U/A	0.3709	U/A
6	U/A	0.3411	U/A	U/A	0.3710	U/A
7	U/A	0.3411	U/A	U/A	0.3710	U/A
8	U/A	0.3410	U/A	U/A	0.3709	U/A

Maximum	0.3412		Maximum	0.3711
Average	0.3411		Average	0.3710

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance Intake			Stem/Guide Clearance Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	U/A	0.0016	U/A	U/A	0.0021	U/A
2	U/A	0.0016	U/A	U/A	0.0030	U/A
3	U/A	0.0014	U/A	U/A	0.0029	U/A
4	U/A	0.0018	U/A	U/A	0.0030	U/A
5	U/A	0.0016	U/A	U/A	0.0023	U/A
6	U/A	0.0017	U/A	U/A	0.0029	U/A
7	U/A	0.0017	U/A	U/A	0.0022	U/A
8	U/A	0.0018	U/A	U/A	0.0030	U/A

Maximum	0.0018
Average	0.0016

Maximum	0.0021
Average	0.0027

Valve Recession Measurement Changes, inches

	Valve Recession Intake			Valve Recession Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	U/A	0.039	U/A	U/A	0.039	U/A
2	U/A	0.059	U/A	U/A	0.032	U/A
3	U/A	0.053	U/A	U/A	0.031	U/A
4	U/A	0.055	U/A	U/A	0.033	U/A
5	U/A	0.056	U/A	U/A	0.062	U/A
6	U/A	0.054	U/A	U/A	0.028	U/A
7	U/A	0.064	U/A	U/A	0.027	U/A
8	U/A	0.064	U/A	U/A	0.029	U/A

Maximum	0.064
Average	0.056

Maximum	0.062
Average	0.035

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	1.76
2	2.00
3	1.56
4	1.88
5	1.43
6	1.62
7	1.54
8	1.64
9	1.39
10	1.45
11	2.28
12	1.60
13	3.46
14	2.18
15	1.65
16	1.54

Maximum	3.46
Average	1.81

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0546	4.0490	0.0055
	2	4.0545	4.0491	0.0054
	3	4.0546	4.0490	0.0055
	4	4.0545	4.0489	0.0056
	5	4.0549	4.0490	0.0058
	6	4.0547	4.0491	0.0056
	7	4.0552	4.0490	0.0062
	8	4.0551	4.0491	0.0059
Post - Test	1	4.0554	4.0488	0.0065
	2	4.0553	4.0490	0.0063
	3	4.0553	4.0487	0.0065
	4	4.0553	4.0487	0.0066
	5	4.0552	4.0490	0.0061
	6	4.0551	4.0491	0.0060
	7	4.0552	4.0488	0.0064
	8	4.0551	4.0491	0.0060

Top and Second Ring Radial Wear, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.17945	0.17885	0.00060
	2	0.17880	0.17845	0.00035
	3	0.17775	0.17735	0.00040
	4	0.17975	0.17935	0.00040
	5	0.17970	0.17900	0.00070
2	1	0.17910	0.17855	0.00055
	2	0.17840	0.17780	0.00060
	3	0.17840	0.17780	0.00060
	4	0.17915	0.17860	0.00055
	5	0.17910	0.17880	0.00030
3	1	0.17850	0.17800	0.00050
	2	0.17840	0.17785	0.00055
	3	0.17860	0.17810	0.00050
	4	0.17860	0.17805	0.00055
	5	0.17920	0.17880	0.00040
4	1	0.17785	0.17750	0.00035
	2	0.17835	0.17480	0.00356
	3	0.17885	0.17840	0.00045
	4	0.17820	0.17790	0.00030
	5	0.17730	0.17680	0.00050
5	1	0.17970	0.17925	0.00045
	2	0.17860	0.17795	0.00065
	3	0.17870	0.17840	0.00030
	4	0.17950	0.17900	0.00050
	5	0.18040	0.17990	0.00050
6	1	0.17955	0.17870	0.00085
	2	0.17970	0.17920	0.00050
	3	0.17930	0.17860	0.00070
	4	0.17925	0.17875	0.00050
	5	0.17940	0.17870	0.00070
7	1	0.17865	0.17825	0.00040
	2	0.17830	0.17785	0.00045
	3	0.17765	0.17750	0.00015
	4	0.17835	0.17805	0.00030
	5	0.17850	0.17825	0.00025
8	1	0.17895	0.17840	0.00055
	2	0.17890	0.17845	0.00045
	3	0.17915	0.17855	0.00060
	4	0.17805	0.17765	0.00040
	5	0.17835	0.17790	0.00045

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16155	0.16100	0.00055
	2	0.16260	0.16200	0.00060
	3	0.16060	0.16025	0.00035
	4	0.15995	0.15945	0.00050
	5	0.16175	0.16110	0.00065
2	1	0.16310	0.16225	0.00085
	2	0.16160	0.16135	0.00025
	3	0.16125	0.16055	0.00070
	4	0.16120	0.16065	0.00055
	5	0.16210	0.16130	0.00080
3	1	0.16185	0.16115	0.00070
	2	0.16190	0.16130	0.00060
	3	0.16035	0.15990	0.00045
	4	0.16080	0.16005	0.00075
	5	0.16200	0.16135	0.00065
4	1	0.16135	0.16110	0.00025
	2	0.16055	0.16010	0.00045
	3	0.16095	0.16065	0.00030
	4	0.16185	0.16155	0.00030
	5	0.16130	0.16085	0.00045
5	1	0.16145	0.16060	0.00085
	2	0.16185	0.16125	0.00060
	3	0.16035	0.15995	0.00040
	4	0.16025	0.15950	0.00075
	5	0.16150	0.16065	0.00085
6	1	0.16175	0.16125	0.00050
	2	0.16115	0.16100	0.00015
	3	0.16075	0.16020	0.00055
	4	0.16115	0.16055	0.00060
	5	0.16120	0.16085	0.00035
7	1	0.16130	0.16070	0.00060
	2	0.15995	0.15980	0.00015
	3	0.16145	0.16095	0.00050
	4	0.16205	0.16160	0.00045
	5	0.16160	0.16085	0.00075
8	1	0.16155	0.16090	0.00065
	2	0.16085	0.16005	0.00080
	3	0.16085	0.16005	0.00080
	4	0.16135	0.16075	0.00060
	5	0.16135	0.16045	0.00090

Top Ring:

Maximum	0.00356
Average	0.00056

Second Ring:

Maximum	0.00090
Average	0.00056

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.017	0.020	0.003
	2	0.039	0.042	0.003
	3	0.016	0.019	0.003
2	1	0.018	0.022	0.004
	2	0.039	0.043	0.004
	3	0.018	0.022	0.004
3	1	0.020	0.022	0.002
	2	0.036	0.042	0.006
	3	0.018	0.022	0.004
4	1	0.022	0.023	0.001
	2	0.038	0.042	0.004
	3	0.018	0.022	0.004
5	1	0.020	0.021	0.001
	2	0.037	0.043	0.006
	3	0.019	0.020	0.001
6	1	0.020	0.024	0.004
	2	0.038	0.044	0.006
	3	0.018	0.021	0.003
7	1	0.020	0.025	0.005
	2	0.039	0.045	0.006
	3	0.020	0.025	0.005
8	1	0.020	0.025	0.005
	2	0.038	0.045	0.007
	3	0.018	0.025	0.007

Ring No. 1 max increase	0.005
Ring No. 2 max increase	0.007
Ring No. 3 max increase	0.007

Ring No. 1 avg increase	0.003
Ring No. 2 avg increase	0.005
Ring No. 3 avg increase	0.004

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.8420	22.7845	0.0575
	2	17.0417	17.0221	0.0196
	3	15.0864	15.0657	0.0207
2	1	22.5783	22.5000	0.0783
	2	17.1162	17.0854	0.0308
	3	15.3148	15.2930	0.0218
3	1	22.8020	22.7304	0.0716
	2	16.9568	16.9291	0.0277
	3	15.3365	15.3121	0.0244
4	1	22.8992	22.8209	0.0783
	2	16.9874	16.9636	0.0238
	3	15.6427	15.6215	0.0212
5	1	22.8418	22.7640	0.0778
	2	16.9759	16.9440	0.0319
	3	15.1376	15.1100	0.0276
6	1	22.8790	22.7950	0.0840
	2	16.9879	16.9611	0.0268
	3	15.5692	15.5479	0.0213
7	1	22.7473	22.6800	0.0673
	2	16.9743	16.9519	0.0224
	3	15.1351	15.1158	0.0193
8	1	22.6606	22.5689	0.0917
	2	16.9474	16.9072	0.0402
	3	15.2944	15.2688	0.0256

Ring No. 1 max decrease	0.0917
Ring No. 2 max decrease	0.0402
Ring No. 3 max decrease	0.0276

Ring No. 1 avg decrease	0.0758
Ring No. 2 avg decrease	0.0279
Ring No. 3 avg decrease	0.0227

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.7072	27.6809	0.0263
	Bottom	27.7140	27.6524	0.0616
2	Top	27.6521	27.6315	0.0206
	Bottom	27.6583	27.6279	0.0304
3	Top	27.6550	27.6372	0.0178
	Bottom	27.6899	27.6620	0.0279
4	Top	27.7184	27.6913	0.0271
	Bottom	27.6500	27.5490	0.1010
5	Top	27.7373	27.7034	0.0339
	Bottom	27.7214	27.6330	0.0884
6	Top	27.6717	27.6527	0.0190
	Bottom	27.6794	27.6423	0.0371
7	Top	27.7136	27.6623	0.0513
	Bottom	27.8515	27.7821	0.0694
8	Top	27.6423	27.6170	0.0253
	Bottom	27.7136	27.6598	0.0538

Maximum	0.1010
Average	0.0432

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.3875	48.3609	0.0266
	Bottom	52.3613	52.2974	0.0639
2	Top	48.3461	48.3290	0.0171
	Bottom	52.3660	52.2829	0.0831
3	Top	98.5120	97.7873	0.7247
	Bottom	104.0810	102.5370	1.5440
4	Top	48.3261	48.3118	0.0143
	Bottom	52.4289	52.3587	0.0702
5	Top	69.5842	69.5415	0.0427
	Bottom	73.4060	73.2868	0.1192

Maximum	1.5440
Average	0.2706

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	SN: 14974651
Test condition :	AL:

PUMP RPM	Description	Spec.	Before	After	Change
1000	Transfer pump psi.	60-62 psi	62	63	-1
	Return Fuel	225-375 cc	350	365	-15
350	Low Idle	12-16 cc	13	13	0
	Housing psi.	8-12 psi	8.5	9	-0.5
	Advance	3.5 deg. min	6.76	6.87	-0.11
	Cold Advance Solenoid	0-1 psi.	0	0	0
750	Shut-Off	4 cc max.	0.5	0.5	0
900	Fuel Delivery	66.5 - 69.5cc	69	68	1
1600	WOT Fuel delivery	59.5 min.	66	66	0
	WOT Advance	2.5 - 3.5 deg.	3.05	3.07	-0.02
	Face Cam Fuel delivery	21.5 - 23.5	22	22	0
	Face Cam Advance	5.25 - 7.25 deg.	6.89	7.06	-0.17
	Low Idle	11 - 12 deg.	11	11	0
1825	Fuel Delivery	33 cc min.	34	33	1
1950	High Idle	15 cc max.	1	2	-1
	Transfer pump psi.	125 psi max.	105	103	2
200	WOT Fuel Delivery	58 cc min.	64	63	1
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	52	52	0
	Transfer pump psi.	16 psi min.	25	25	0
	Housing psi.	0 -12 psi	8	7	1
	Air Timing	-.5 deg.(+/-.5 deg)	-1	-1	0
	Fluid Temp. Deg. C				
	Date		10/1/09	4/22/10	

*Pump calibration data to be used for reference only

Photographs

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-241026	**EOT Date:**	04/09/10
Test No.:	LO241026-65T1-W-210	**Test Length:**	140

Piston Skirt Thrust - Best Cyl 4

Piston Skirt Anti-thrust - Best Cyl 4

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-241026	EOT Date:	04/09/10
Test No.:	LO241026-65T1-W-210	Test Length:	140

Piston Skirt Thrust - Worst Cyl 8

Piston Skirt Anti-thrust - Worst Cyl 8

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-241026	EOT Date:	04/09/10
Test No.:	LO241026-65T1-W-210	Test Length:	140

Piston Rings - Best Cyl 1

Piston Rings - Worst Cyl 8

Oil Code:	LO-241026	**EOT Date:**	04/09/10
Test No.:	LO241026-65T1-W-210	**Test Length:**	140

Piston Undercrown - Best Cyl 4

Piston Undercrown - Worst Cyl 8

Oil Code:	LO-241026	EOT Date:	04/09/10
Test No.:	LO241026-65T1-W-210	Test Length:	140

Engine Block Cylinder Bore - Best Cyl 7

Engine Block Cylinder Bore - Worst Cyl 1

Oil Code:	LO-241026	**EOT Date:**	04/09/10
Test No.:	LO241026-65T1-W-210	**Test Length:**	140

Exhaust and Intake Valve - Best Cyl 8

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-241026	**EOT Date:**	04/09/10
Test No.:	LO241026-65T1-W-210	**Test Length:**	140

Exhaust and Intake Valve - Worst Cyl 1

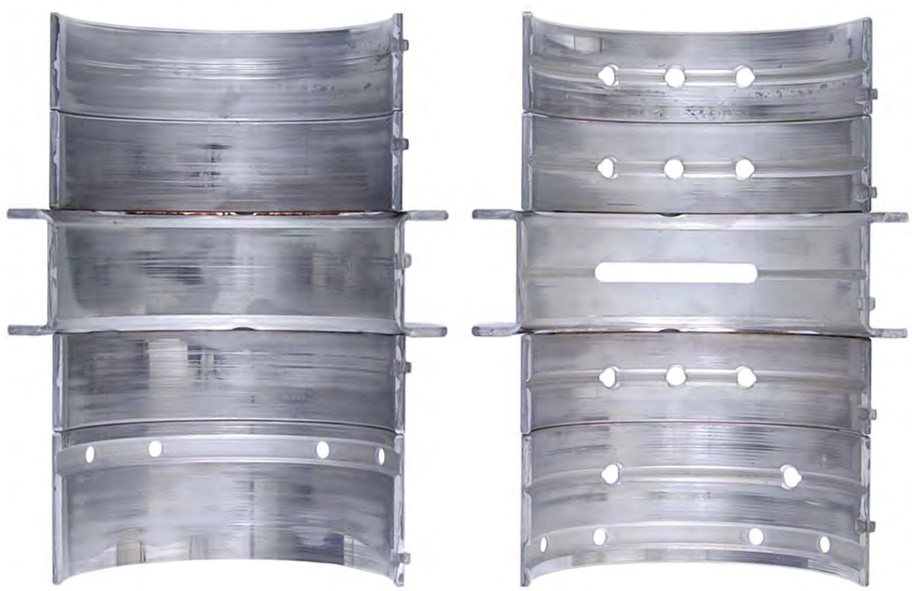
Oil Code:	LO-241026	**EOT Date:**	04/09/10
Test No.:	LO241026-65T1-W-210	**Test Length:**	140

Rod Bearings

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-241026	**EOT Date:**	04/09/10
Test No.:	LO241026-65T1-W-210	**Test Length:**	140

Main Bearings



APPENDIX A2. – MIL-PRF-46167 OEA, REPEATABILITY RUN 2 OF 3

REPEATABILITY EVALUATION 2 OF 3
MIL-PRF-46167D
OEA-30 ARCTIC OIL

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-241026
Arctic Oil – OEA30
Test Fuel: Jet-A w/DCI-4A
Test Number: LO241026-65T2-W-210
Start of Test Date: April 19, 2010
End of Test Date: May 03, 2010
Test Duration: 140 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the statistical repeatability of MIL-PRF-46167D OEA-30 arctic oil when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

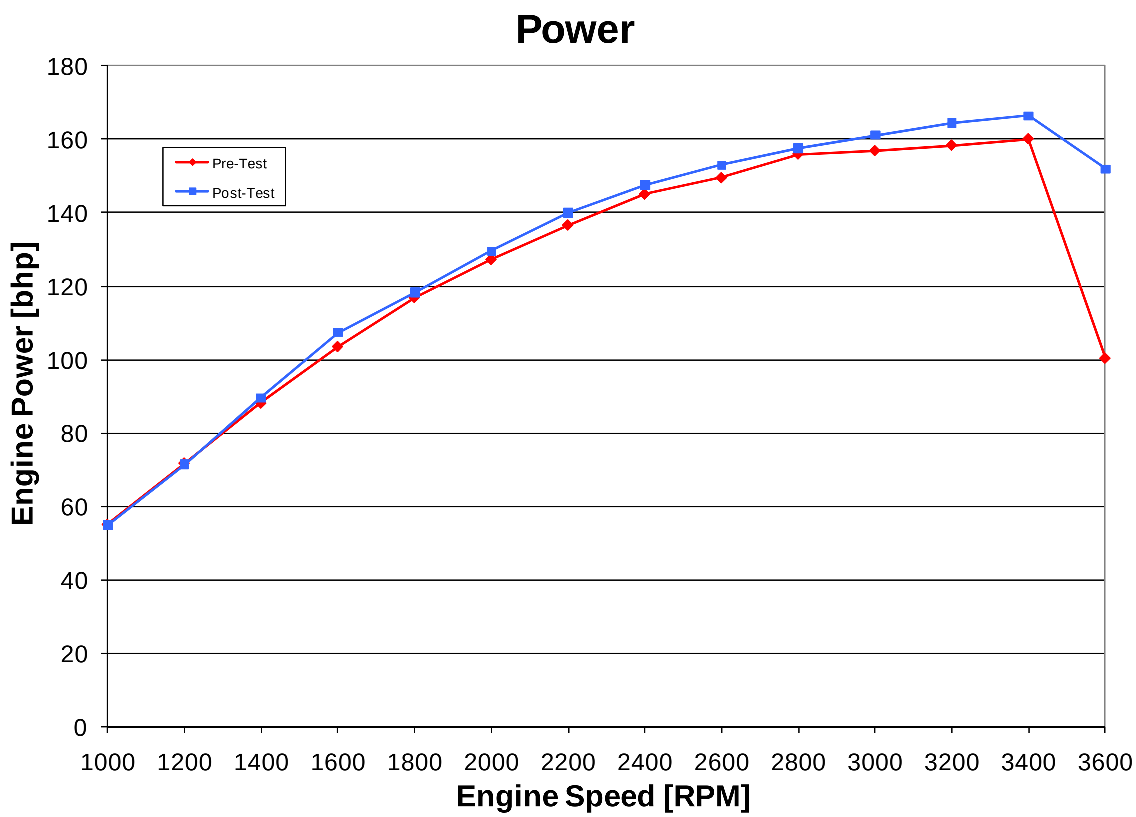
Engine Operating Conditions Summary

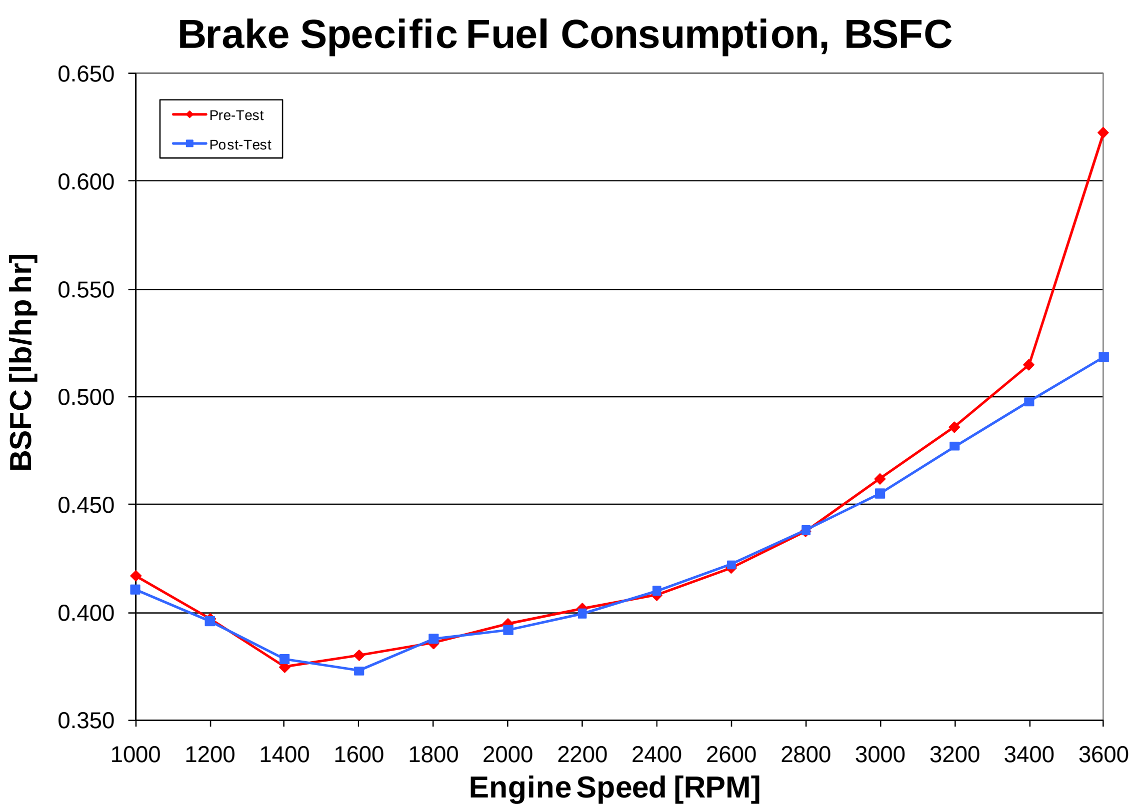
Below is a summary of the engine operating conditions over the test duration. Testing was stopped at 140hrs due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.02	0.75	900.08	1.51
Torque*	ft*lb	256.41	4.72	29.12	2.42
Fuel Flow	lb/hr	81.53	2.92	6.16	0.39
Power*	bhp	165.99	3.05	4.99	0.41
BSFC*	lb/bhp*hr	0.491	0.018	1.240	0.100
Temperatures:					
Coolant In	°F	191.52	0.99	92.40	0.95
Coolant Out	°F	205.04	0.85	99.77	0.74
Oil Sump	°F	259.90	1.79	125.51	1.78
Fuel In	°F	95.34	0.93	94.98	0.35
Intake Air	°F	82.03	5.99	79.65	5.98
Cylinder 1 Exhaust	°F	1077.39	19.14	171.64	7.62
Cylinder 2 Exhaust	°F	1197.34	18.56	196.22	4.95
Cylinder 3 Exhaust	°F	1217.78	18.61	187.13	5.08
Cylinder 4 Exhaust	°F	1177.12	20.40	192.11	6.47
Cylinder 5 Exhaust	°F	1184.86	25.62	180.38	7.30
Cylinder 6 Exhaust	°F	1154.17	31.81	188.81	5.00
Cylinder 7 Exhaust	°F	1192.20	26.65	179.76	6.41
Cylinder 8 Exhaust	°F	1212.57	20.18	189.40	6.50
Pressures:					
Oil Galley	psi	36.43	0.68	38.01	3.09
Ambient Pressure	psiA	14.16	0.10	14.15	0.10
Boost Pressure	psi	5.06	0.11	-0.06	0.06

* Non-corrected Values

Engine Performance Curves

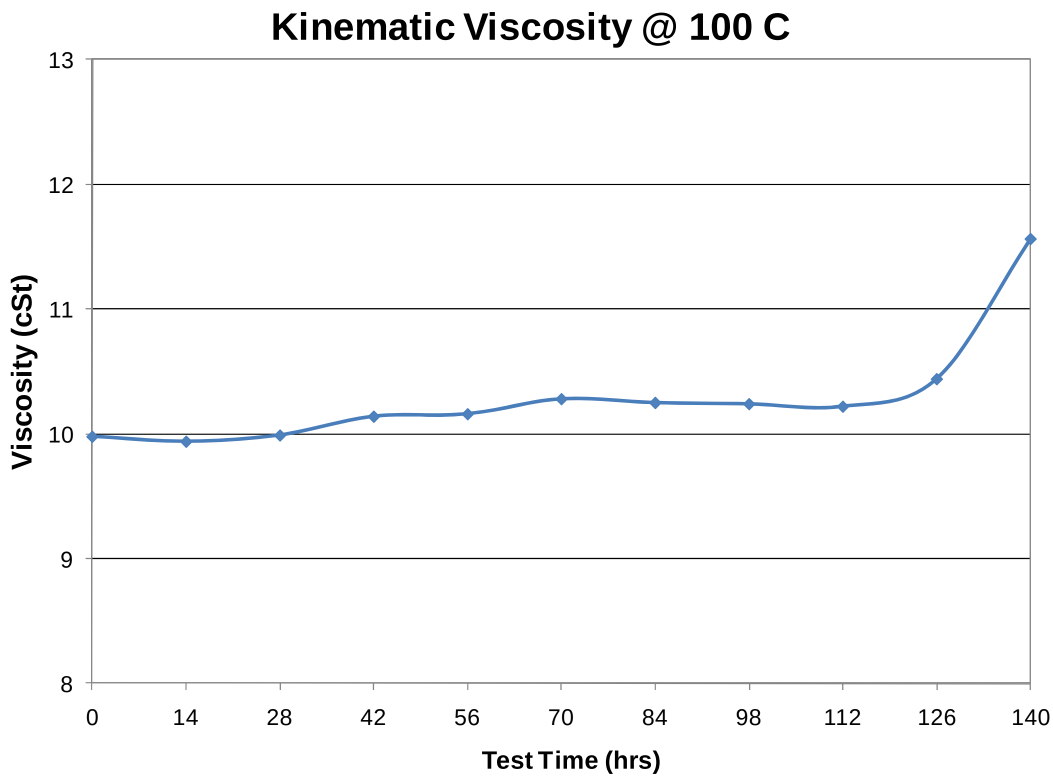


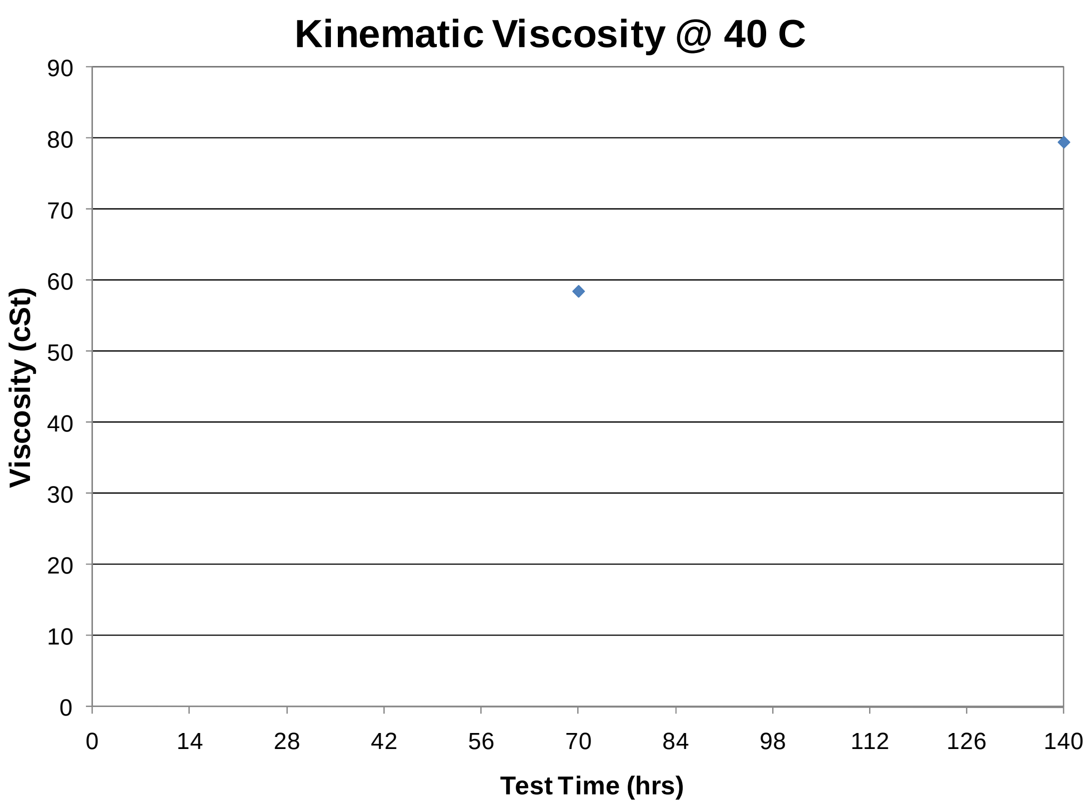


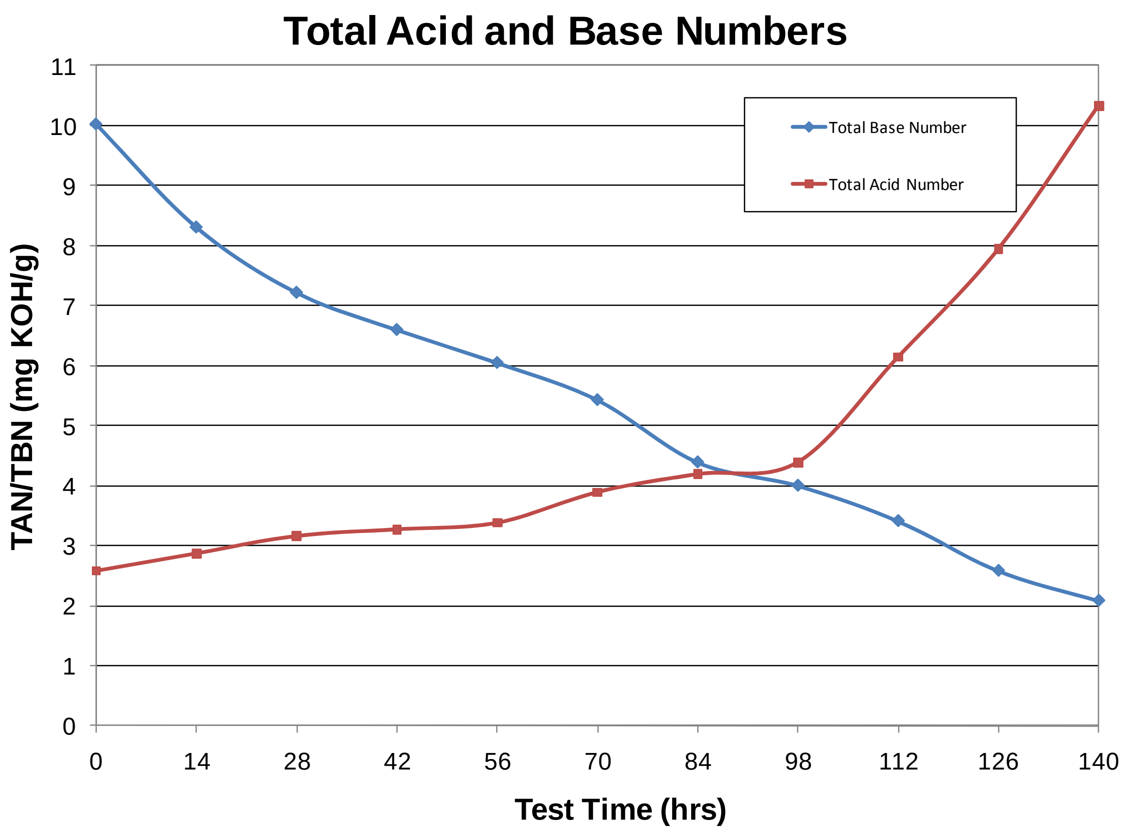
Engine Oil Analysis

Property	ASTM Test	Test Hours										
		0	14	28	42	56	70	84	98	112	126	140
Density	D4052	0.849	0.850	0.854	0.855	0.857	0.860	0.863	0.865	0.870	0.879	0.891
Viscosity @ 100°C (cSt)	D445	10.0	9.9	10.0	10.1	10.2	10.3	10.3	10.2	10.2	10.4	11.6
Viscosity @ 40°C (cSt)	D445						58.5					79.5
Viscosity Index (dyne/cm)	D2270	0.0	0.0	0.0	0.0	0.0	165.0	0.0	0.0	0.0	0.0	138.0
Total Base Number (mg KOH/g)	D4739	10.0	8.3	7.2	6.6	6.1	5.4	4.4	4.0	3.4	2.6	2.1
Total Acid Number (mg KOH/g)	D664	2.6	2.9	3.2	3.3	3.4	3.9	4.2	4.4	6.1	7.9	10.3
Oxidation (Abs./cm)	E168 FTNG	0.0	4.9	10.1	14.4	19.0	24.2	31.6	39.5	55.1	90.4	137.9
Nitration (Abs./cm)	E168 FTNG	0.0	3.6	3.6	3.4	4.9	7.6	11.5	15.2	26.3	39.1	47.0
Soot	Soot	0.1	0.4	0.4	0.5	0.6	0.8	1.0	1.0	1.3	1.3	1.8
Wear Metals (ppm)	D5185											
Al		1	2	2	3	3	3	3	4	4	4	5
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		4	1	2	3	4	4	3	3	5	4	8
Ca		3411	3626	3767	3945	4143	4184	4263	4565	4670	4910	4972
Cr		<1	1	2	3	4	4	6	6	7	8	8
Cu		<1	35	39	42	45	46	47	49	52	85	203
Fe		2	45	75	102	126	150	181	220	264	353	492
Pb		<1	12	13	15	17	19	26	31	50	136	355
Mg		12	13	13	14	15	15	16	17	18	19	20
Mn		<1	2	2	3	3	3	4	4	5	6	7
Mo		<1	8	13	16	19	21	24	25	27	29	31
Ni		<1	2	3	4	4	5	6	6	7	7	8
P		1225	1212	1159	1172	1194	1216	1239	1330	1329	1400	1397
Si		5	17	20	20	19	20	22	22	23	23	24
Ag		1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		<5	<5	8	5	7	6	5	8	8	10	7
Sn		<1	8	10	11	13	13	14	15	18	20	21
Zn		1396	1473	1479	1542	1587	1632	1682	1781	1816	1899	1970
K		6	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sr		1	1	2	1	1	1	2	1	2	2	1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2

Engine Oil Analysis Trends



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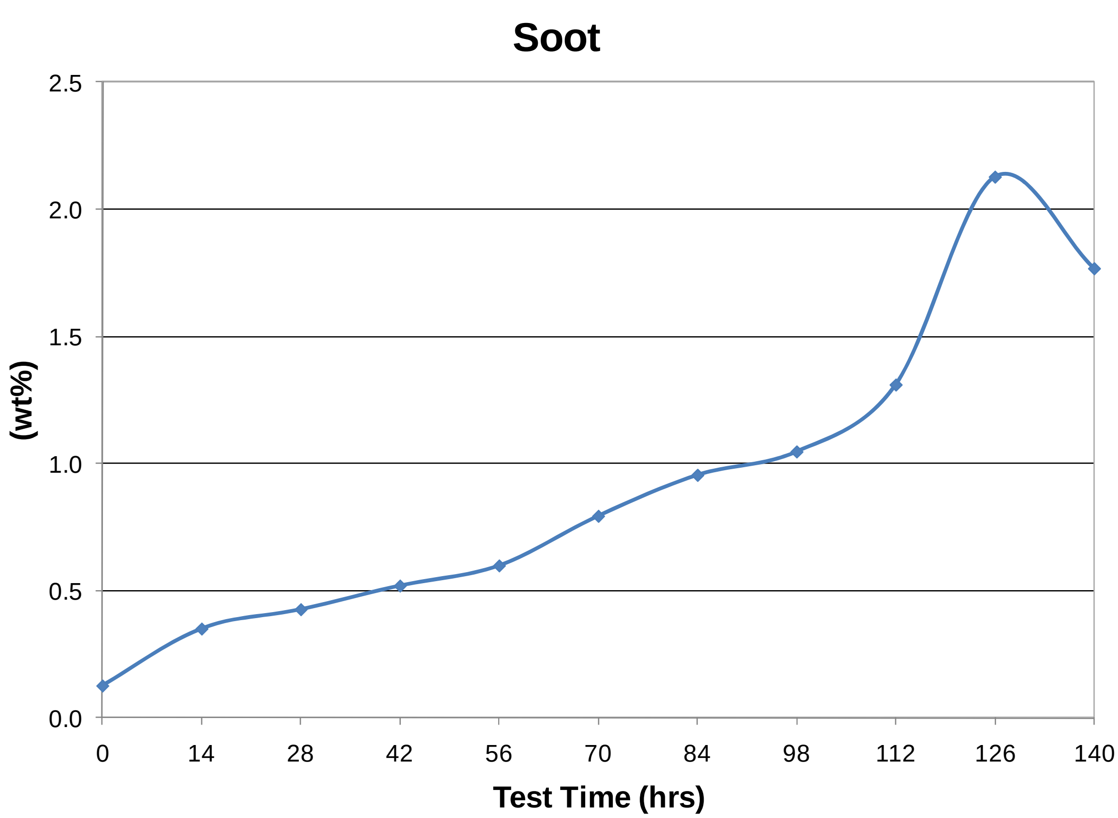
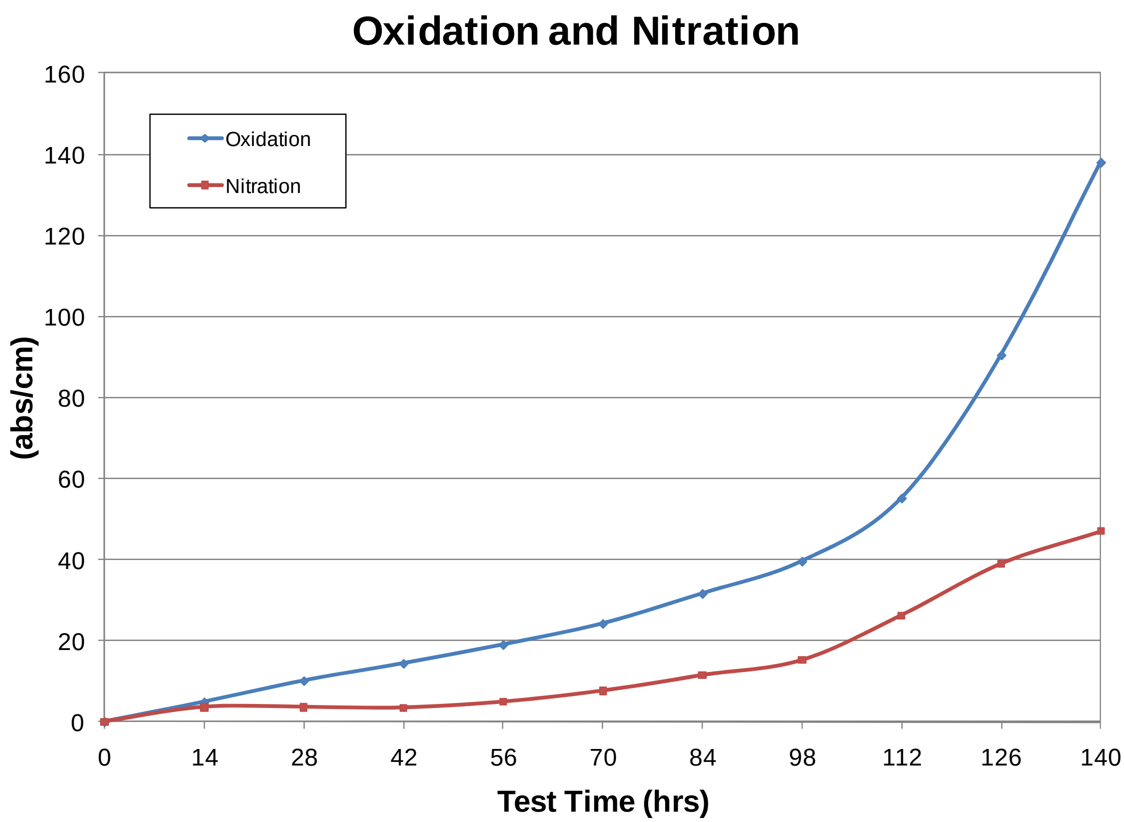
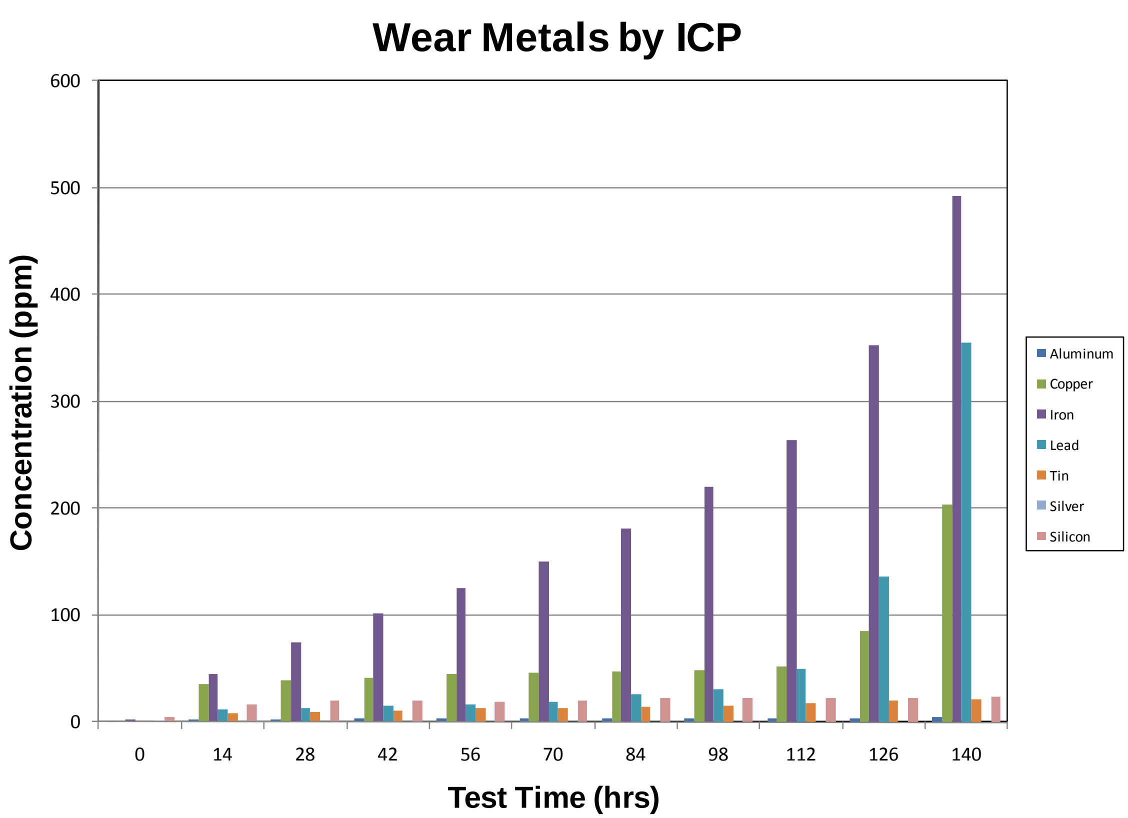
TAN/TBN (mg KOH/g)
Test Time (hrs)
Total Base Number
Total Acid Number
0
1
2
3
4
5
6
7
8
9
10
11
0
14
28
42
56
70
84
98
112
126
140


Soot
(wt%)
Test Time (hrs)
0.0
0.5
1.0
1.5
2.0
2.5
0
14
28
42
56
70
84
98
112
126
140


Oxidation and Nitration
160
140
120
100
80
60
40
20
0
(abs/cm)
Oxidation
Nitration
0
14
28
42
56
70
84
98
112
126
140
Test Time (hrs)


Wear Metals by ICP
600
500
400
300
200
100
0
Concentration (ppm)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon
0
14
28
42
56
70
84
98
112
126
140
Test Time (hrs)

Oil Consumption Data

Average oil consumption per test hour was 0.082 lbs/hr.

Hour	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Cosumption Accumulated
0	0	0	0	0
14	1.42	0.24	1.18	1.18
28	1.48	0.24	1.24	2.42
42	1.41	0.23	1.18	3.6
56	1.57	0.24	1.33	4.93
70	1.24	0.25	0.99	5.92
84	1.64	0.24	1.4	7.32
98	1.31	0.24	1.07	8.39
112	1.28	0.24	1.04	9.43
126	1.68	0.24	1.44	10.87
140	1.56	0.25	1.31	12.18
	Initial Fill	16.01	**Total Additions**	14.59
	EOT Drain	15.73	**Total Samples**	2.41
	Dry Filter	0.73	**Wet Filter**	1.78

(Initial Fill + Additions+Dry Filter)	31.33
(EOT Drain + Samples+Wet Filter)	19.92
Total Oil Consumption	11.41

Post Test Engine Ratings

Ratings	Clyinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	No	No	No	No	No	No	No	No	--
Ring No.2	No	No	No	No	No	No	No	No	--
Ring No.3	No	No	No	No	No	No	No	No	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	55.25	53.50	37.25	26.25	28.50	32.25	48.25	49.25	41.31
No.2 Groove	6.25	1.00	9.25	0.50	7.25	5.00	14.00	7.28	6.32
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	42.25	34.25	30.50	35.25	42.00	44.25	57.00	29.75	39.41
No.2 Land	17.75	4.00	23.75	10.00	17.75	16.50	29.50	29.50	18.59
No.3 Land	0.75	0.00	0.00	0.00	4.25	1.75	0.00	4.25	1.38
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.50	1.56
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	2.13	2.57	2.25	2.17	2.76	4.45	2.27	3.80	2.80
No.3 Groove	2.08	2.70	2.98	2.40	2.98	3.03	3.32	4.17	2.96
No.1 Land	0.00	0.22	0.19	0.16	0.31	0.16	0.20	1.20	0.31
No.2 Land	1.51	2.93	1.85	1.50	0.77	1.59	0.78	0.81	1.47
No.3 Land	2.75	2.81	3.52	2.35	1.75	3.20	2.79	2.50	2.71
Upper Skirt	1.76	2.26	1.72	0.55	0.70	1.08	0.80	1.46	1.29
Under Crown	3.78	4.83	4.98	5.72	3.87	3.30	4.46	1.55	4.06
Front Pin Bore	1.61	2.16	1.14	0.93	1.10	1.36	1.47	1.47	1.41
Rear Pin Bore	1.70	2.21	1.89	1.13	1.10	1.36	1.47	1.47	1.54
Total, Demerits	139.57	115.44	121.27	88.91	115.09	119.28	166.31	150.96	127.10
Miscellanous									
Top Groove Fill, %	67	62	28	16	15	29	40	40	37.13
Intermediate Groove Fill, %	2	0	7	0	2	1	4	1	2.13
Top Land Heavy Carbon, %	23	15	10	15	25	27	44	16	21.88
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0	0	0.00
Valve Tulip Deposits, Merits									
Exahust	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.1	9.01
Intake	8.7	8.5	7.6	8.7	8.7	8.7	8.7	8.6	8.53

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0546	4.0552	4.0548	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0001	0.0009	0.0004	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0000	0.0005	0.0003	
Piston Skirt Diameter	4.0498	4.0499	4.0499	
Piston Skirt to Cylinder Bore Clearance	0.0046	0.0053	0.0050	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.016	0.020	0.018	
Second Ring	0.038	0.039	0.038	
Oil Control Ring	0.016	0.018	0.018	
Ring To Groove Clearance				
Second Ring	0.0015	0.0020	0.0018	0.0015"-0.003"
Oil Control Ring	0.0020	0.0020	0.0020	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2180	1.2191	1.2184	1.2203"-1.2206"
Piston Bore Diameter	1.2213	1.2218	1.2215	1.2207"-1.2212"
Piston Pin Clearance	0.0033	0.0027	0.0031	0.0003"-0.0012"
Bearing Clearances				
Connecting Rod to Journal	0.0020	0.0020	0.0020	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0035	0.0023	0.001"-0.005"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0550	4.0547		0.0003
	Middle	4.0548	4.0542	4.0548	0.0006
	Bottom	4.0548	4.0546		0.0002
	Taper	0.0002	0.0005		
2	Top	4.0548	4.0545		0.0003
	Middle	4.0546	4.0541	4.0546	0.0005
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0003	0.0004		
3	Top	4.0551	4.0546		0.0005
	Middle	4.0549	4.0543	4.0549	0.0006
	Bottom	4.0548	4.0546		0.0002
	Taper	0.0003	0.0003		
4	Top	4.0549	4.0544		0.0005
	Middle	4.0546	4.0541	4.0546	0.0005
	Bottom	4.0546	4.0544		0.0002
	Taper	0.0003	0.0003		
5	Top	4.0551	4.0544		0.0007
	Middle	4.0550	4.0541	4.0549	0.0009
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0003	0.0004		
6	Top	4.0549	4.0545		0.0004
	Middle	4.0547	4.0544	4.0547	0.0003
	Bottom	4.0546	4.0543		0.0003
	Taper	0.0003	0.0002		
7	Top	4.0552	4.0551		0.0001
	Middle	4.0552	4.0551	4.0552	0.0001
	Bottom	4.0552	4.0548		0.0004
	Taper	0.0000	0.0003		
8	Top	4.0553	4.0549		0.0004
	Middle	4.0552	4.0546	4.0551	0.0006
	Bottom	4.0550	4.0549		0.0001
	Taper	0.0003	0.0003		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0547	4.0553		0.0006
	Middle	4.0541	4.0549	4.0544	0.0008
	Bottom	4.0547	4.0549		0.0002
	Taper	0.0006	0.0004		
2	Top	4.0547	4.0553		0.0006
	Middle	4.0542	4.0548	4.0544	0.0006
	Bottom	4.0546	4.0547		0.0001
	Taper	0.0005	0.0006		
3	Top	4.0546	4.0553		0.0007
	Middle	4.0542	4.0551	4.0544	0.0009
	Bottom	4.0546	4.0548		0.0002
	Taper	0.0004	0.0005		
4	Top	4.0546	4.0551		0.0005
	Middle	4.0542	4.0548	4.0545	0.0006
	Bottom	4.0547	4.0547		0.0000
	Taper	0.0005	0.0004		
5	Top	4.0543	4.0554		0.0011
	Middle	4.0540	4.0551	4.0544	0.0011
	Bottom	4.0547	4.0550		0.0003
	Taper	0.0007	0.0004		
6	Top	4.0544	4.0553		0.0009
	Middle	4.0541	4.0549	4.0544	0.0008
	Bottom	4.0546	4.0548		0.0002
	Taper	0.0005	0.0005		
7	Top	4.0551	4.0556		0.0005
	Middle	4.0547	4.0554	4.0549	0.0007
	Bottom	4.0550	4.0553		0.0003
	Taper	0.0004	0.0003		
8	Top	4.0551	4.0555		0.0004
	Middle	4.0546	4.0553	4.0548	0.0007
	Bottom	4.0550	4.0552		0.0002
	Taper	0.0005	0.0003		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0003	0.0006	
	Middle	0.0007	0.0007	0.0004
	Bottom	0.0001	0.0003	
2	Top	0.0001	0.0008	
	Middle	0.0004	0.0007	0.0002
	Bottom	0.0001	0.0003	
3	Top	0.0005	0.0007	
	Middle	0.0007	0.0008	0.0005
	Bottom	0.0002	0.0002	
4	Top	0.0003	0.0007	
	Middle	0.0004	0.0007	0.0003
	Bottom	0.0001	0.0003	
5	Top	0.0008	0.0010	
	Middle	0.0010	0.0010	0.0005
	Bottom	0.0001	0.0005	
6	Top	0.0005	0.0008	
	Middle	0.0006	0.0005	0.0003
	Bottom	0.0000	0.0005	
7	Top	0.0001	0.0005	
	Middle	0.0005	0.0003	0.0004
	Bottom	0.0002	0.0005	
8	Top	0.0002	0.0006	
	Middle	0.0006	0.0007	0.0003
	Bottom	0.0000	0.0003	
Avgerage All Cylinders	Top	0.0003	0.0007	
	Middle	0.0006	0.0007	
	Bottom	0.0001	0.0004	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	U/A	0.3461	U/A	U/A	0.3763	U/A
2	U/A	0.3461	U/A	U/A	0.3764	U/A
3	U/A	0.3461	U/A	U/A	0.3764	U/A
4	U/A	0.3461	U/A	U/A	0.3764	U/A
5	U/A	0.3461	U/A	U/A	0.3764	U/A
6	U/A	0.3461	U/A	U/A	0.3764	U/A
7	U/A	0.3461	U/A	U/A	0.3764	U/A
8	U/A	0.3461	U/A	U/A	0.3764	U/A

	Intake		Exhaust
Maximum	0.3461	Maximum	0.3764
Average	0.3461	Average	0.3764

Valve Stem Measurement Changes, inches

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	U/A	0.3413	U/A	U/A	0.3717	U/A
2	U/A	0.3412	U/A	U/A	0.3716	U/A
3	U/A	0.3413	U/A	U/A	0.3715	U/A
4	U/A	0.3413	U/A	U/A	0.3715	U/A
5	U/A	0.3412	U/A	U/A	0.3715	U/A
6	U/A	0.3413	U/A	U/A	0.3714	U/A
7	U/A	0.3413	U/A	U/A	0.3715	U/A
8	U/A	0.3413	U/A	U/A	0.3715	U/A

Maximum	0.3413	Maximum	0.3717
Average	0.3413	Average	0.3715

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance Intake			Stem/Guide Clearance Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	U/A	0.0048	U/A	U/A	0.0046	U/A
2	U/A	0.0049	U/A	U/A	0.0048	U/A
3	U/A	0.0048	U/A	U/A	0.0049	U/A
4	U/A	0.0048	U/A	U/A	0.0049	U/A
5	U/A	0.0049	U/A	U/A	0.0049	U/A
6	U/A	0.0048	U/A	U/A	0.0050	U/A
7	U/A	0.0048	U/A	U/A	0.0049	U/A
8	U/A	0.0048	U/A	U/A	0.0049	U/A

	Intake		Exahust
Maximum	0.0049	Maximum	0.0046
Average	0.0048	Average	0.0049

Valve Recession Measurement Changes, inches

	Valve Recession Intake			Valve Recession Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	U/A	0.0560	U/A	U/A	0.0252	U/A
2	U/A	0.0490	U/A	U/A	0.0275	U/A
3	U/A	0.0534	U/A	U/A	0.0392	U/A
4	U/A	0.0541	U/A	U/A	0.0364	U/A
5	U/A	0.0582	U/A	U/A	0.0437	U/A
6	U/A	0.0521	U/A	U/A	0.0264	U/A
7	U/A	0.0608	U/A	U/A	0.0293	U/A
8	U/A	0.0678	U/A	U/A	0.0298	U/A

	Intake		Exahust
Maximum	0.0678	Maximum	0.0437
Average	0.0564	Average	0.0322

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	1.41
2	1.37
3	1.01
4	1.13
5	0.91
6	0.99
7	1.35
8	1.04
9	1.29
10	1.64
11	1.48
12	1.64
13	1.19
14	1.57
15	1.17
16	1.42

Maximum	1.64
Average	1.29

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0548	4.0499	0.0049
	2	4.0546	4.0499	0.0046
	3	4.0549	4.0499	0.0050
	4	4.0546	4.0498	0.0048
	5	4.0549	4.0498	0.0051
	6	4.0547	4.0498	0.0049
	7	4.0552	4.0499	0.0053
	8	4.0551	4.0498	0.0053
Post - Test	1	4.0544	4.0493	0.0051
	2	4.0544	4.0490	0.0054
	3	4.0544	4.0490	0.0054
	4	4.0545	4.0487	0.0057
	5	4.0544	4.0490	0.0053
	6	4.0544	4.0487	0.0056
	7	4.0549	4.0489	0.0060
	8	4.0548	4.0490	0.0058

Top and Second Ring Radial Wear, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.17995	0.17965	0.00030
	2	0.18000	0.17960	0.00040
	3	0.17780	0.17760	0.00020
	4	0.17820	0.17790	0.00030
	5	0.17880	0.17850	0.00030
2	1	0.18075	0.18045	0.00030
	2	0.17845	0.17795	0.00050
	3	0.17835	0.17785	0.00050
	4	0.18080	0.18040	0.00040
	5	0.18100	0.18060	0.00040
3	1	0.17890	0.17860	0.00030
	2	0.17970	0.17925	0.00045
	3	0.18030	0.17985	0.00045
	4	0.18020	0.17970	0.00050
	5	0.17945	0.17895	0.00050
4	1	0.17800	0.17775	0.00025
	2	0.17830	0.17780	0.00050
	3	0.18000	0.17960	0.00040
	4	0.17785	0.17745	0.00040
	5	0.17890	0.17865	0.00025
5	1	0.17745	0.17695	0.00050
	2	0.17860	0.17815	0.00045
	3	0.17875	0.17825	0.00050
	4	0.17785	0.17720	0.00065
	5	0.17715	0.17665	0.00050
6	1	0.17905	0.17880	0.00025
	2	0.17885	0.17830	0.00055
	3	0.17890	0.17860	0.00030
	4	0.17950	0.17895	0.00055
	5	0.17925	0.17905	0.00020
7	1	0.17945	0.17890	0.00055
	2	0.18025	0.17970	0.00055
	3	0.17990	0.17960	0.00030
	4	0.18025	0.17995	0.00030
	5	0.17980	0.17935	0.00045
8	1	0.18150	0.18060	0.00090
	2	0.18010	0.17915	0.00095
	3	0.17880	0.17820	0.00060
	4	0.17830	0.17770	0.00060
	5	0.17985	0.17930	0.00055

Maximum	0.00095
Average	0.00044

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16335	0.16280	0.00055
	2	0.16300	0.16265	0.00035
	3	0.16225	0.16160	0.00065
	4	0.16235	0.16180	0.00055
	5	0.16265	0.16215	0.00050
2	1	0.16160	0.16100	0.00060
	2	0.16175	0.16120	0.00055
	3	0.16170	0.16105	0.00065
	4	0.16040	0.15975	0.00065
	5	0.16140	0.16075	0.00065
3	1	0.16260	0.16200	0.00060
	2	0.16275	0.16210	0.00065
	3	0.16290	0.16215	0.00075
	4	0.16275	0.16220	0.00055
	5	0.16240	0.16180	0.00060
4	1	0.16115	0.16055	0.00060
	2	0.16130	0.16100	0.00030
	3	0.16140	0.16090	0.00050
	4	0.16085	0.16020	0.00065
	5	0.16120	0.16065	0.00055
5	1	0.16280	0.16235	0.00045
	2	0.16275	0.16255	0.00020
	3	0.16080	0.16040	0.00040
	4	0.16120	0.16075	0.00045
	5	0.16280	0.16215	0.00065
6	1	0.16165	0.16095	0.00070
	2	0.16145	0.16085	0.00060
	3	0.16070	0.16015	0.00055
	4	0.16020	0.15950	0.00070
	5	0.16160	0.16080	0.00080
7	1	0.16295	0.16230	0.00065
	2	0.16335	0.16275	0.00060
	3	0.16360	0.16290	0.00070
	4	0.16255	0.16185	0.00070
	5	0.16240	0.16165	0.00075
8	1	0.16075	0.15980	0.00095
	2	0.16105	0.16035	0.00070
	3	0.16105	0.16025	0.00080
	4	0.16095	0.16030	0.00065
	5	0.16145	0.16060	0.00085

Maximum	0.00095
Average	0.00061

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.019	0.020	0.001
	2	0.039	0.430	0.391
	3	0.018	0.019	0.001
2	1	0.016	0.018	0.002
	2	0.038	0.043	0.005
	3	0.017	0.021	0.004
3	1	0.018	0.019	0.001
	2	0.038	0.045	0.007
	3	0.018	0.020	0.002
4	1	0.018	0.021	0.003
	2	0.038	0.043	0.005
	3	0.018	0.020	0.002
5	1	0.018	0.022	0.004
	2	0.038	0.044	0.006
	3	0.017	0.021	0.004
6	1	0.020	0.023	0.003
	2	0.039	0.043	0.004
	3	0.018	0.020	0.002
7	1	0.018	0.023	0.005
	2	0.039	0.045	0.006
	3	0.016	0.023	0.007
8	1	0.018	0.020	0.002
	2	0.038	0.045	0.007
	3	0.018	0.020	0.002

Ring No. 1 max increase	0.005
Ring No. 2 max increase	0.391
Ring No. 3 max increase	0.007

Ring No. 1 avg increase	0.003
Ring No. 2 avg increase	0.054
Ring No. 3 avg increase	0.003

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.8265	22.7755	0.0510
	2	17.0474	17.0238	0.0236
	3	14.7650	14.7500	0.0150
2	1	23.0049	22.9384	0.0665
	2	16.9273	16.8979	0.0294
	3	14.9592	14.9417	0.0175
3	1	23.0256	22.9450	0.0806
	2	17.0379	17.0035	0.0344
	3	14.8297	14.8081	0.0216
4	1	22.8181	22.7639	0.0542
	2	16.9180	16.8992	0.0188
	3	15.2769	15.2605	0.0164
5	1	22.7328	22.6521	0.0807
	2	17.0117	16.9772	0.0345
	3	15.1952	15.1729	0.0223
6	1	22.7715	22.7010	0.0705
	2	16.8894	16.8650	0.0244
	3	14.9596	14.9398	0.0198
7	1	22.7769	22.6890	0.0879
	2	17.0950	17.0606	0.0344
	3	15.3439	15.3234	0.0205
8	1	22.9617	22.8566	0.1051
	2	16.8368	16.8037	0.0331
	3	15.2107	15.1843	0.0264

Ring No. 1 max decrease	0.1051
Ring No. 2 max decrease	0.0345
Ring No. 3 max decrease	0.0264

Ring No. 1 avg decrease	0.0746
Ring No. 2 avg decrease	0.0291
Ring No. 3 avg decrease	0.0199

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.6668	27.6520	0.0148
	Bottom	27.6849	27.6699	0.0150
2	Top	27.8245	27.8080	0.0165
	Bottom	27.7339	27.7252	0.0087
3	Top	27.7148	27.6913	0.0235
	Bottom	27.7615	27.7388	0.0227
4	Top	27.7439	27.7197	0.0242
	Bottom	27.8248	27.8058	0.0190
5	Top	27.8365	27.8177	0.0188
	Bottom	27.6950	27.6763	0.0187
6	Top	27.7980	27.7807	0.0173
	Bottom	27.7957	27.7698	0.0259
7	Top	27.8110	27.6739	0.1371
	Bottom	27.6665	27.6086	0.0579
8	Top	27.6869	27.6671	0.0198
	Bottom	27.7249	27.7119	0.0130

Maximum	0.1371
Average	0.0283

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.2361	48.2015	0.0346
	Bottom	52.6682	52.5930	0.0752
2	Top	48.2012	48.1808	0.0204
	Bottom	52.6849	52.5564	0.1285
3	Top	93.6209	92.1906	1.4303
	Bottom	99.9640	98.0709	1.8931
4	Top	48.2976	48.2798	0.0178
	Bottom	52.7599	52.7091	0.0508
5	Top	69.1458	69.0821	0.0637
	Bottom	73.1816	73.0705	0.1111

Maximum	1.8931
Average	0.3826

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 15067487**
Test condition :	**AL:**

PUMP RPM	*Description*	*Spec.*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60-62 psi	62	62	0
	Return Fuel	225-375 cc	300	384	-84
350	Low Idle	12-16 cc	15	14	1
	Housing psi.	8-12 psi	9	8.5	0.5
	Advance	3.5 deg. min	5.8	4.95	0.85
	Cold Advance Solenoid	0-1 psi.	0	0	0
750	Shut-Off	4 cc max.	0	0.5	-0.5
900	Fuel Delivery	66.5 - 69.5cc	67	67	0
1600	WOT Fuel delivery	59.5 min.	64	63	1
	WOT Advance	2.5 - 3.5 deg.	3.07	2.87	0.2
	Face Cam Fuel delivery	21.5 - 23.5	22	22	0
	Face Cam Advance	5.25 - 7.25 deg.	6.12	6.65	-0.53
	Low Idle	11 - 12 deg.	10.6	11.29	-0.69
1825	Fuel Delivery	33 cc min.	38	48	-10
1950	High Idle	15 cc max.	3	3	0
	Transfer pump psi.	125 psi max.	101	102	-1
200	WOT Fuel Delivery	58 cc min.	63	63	0
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	54	54	0
	Transfer pump psi.	16 psi min.	26	24	2
	Housing psi.	0 -12 psi	2	6	-4
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5		
	Fluid Temp. Deg. C				
	Date		1/20/2010	5/18/2010	

*Pump calibration data to be used for reference only

Photographs

Oil Code:	LO-241026	**EOT Date:**	4/19/10
Test No.:	LO241026-65T2_WVC	**Test Length:**	140

Piston Skirt Thrust - Best Cyl 4

Piston Skirt Anti-thrust - Best Cyl 4

Oil Code:	LO-241026	EOT Date:	4/19/10
Test No.:	LO241026-65T2_WVC	Test Length:	140

Piston Skirt Thrust - Worst Cyl 7

Piston Skirt Anti-thrust - Worst Cyl 7

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-241026	**EOT Date:**	4/19/10
Test No.:	LO241026-65T2_WVC	**Test Length:**	140

Piston Rings - Best Cyl 4

Piston Rings - Worst Cyl 8

Oil Code:	LO-241026	**EOT Date:**	4/19/10
Test No.:	LO241026-65T2_WVC	**Test Length:**	140

Piston Undercrown - Best Cyl 4

Piston Undercrown - Worst Cyl 7

Oil Code:	LO-241026	**EOT Date:**	4/19/10
Test No.:	LO241026-65T2_WVC	**Test Length:**	140

Engine Block Cylinder Bore - Best   Cyl 6

Engine Block Cylinder Bore - Worst   Cyl 7

Oil Code:	LO-241026	**EOT Date:**	4/19/10
Test No.:	LO241026-65T2_WVC	**Test Length:**	140

Exhaust and Intake Valve - Best Cyl 4

Oil Code:	LO-241026	EOT Date:	4/19/10
Test No.:	LO241026-65T2_WVC	Test Length:	140

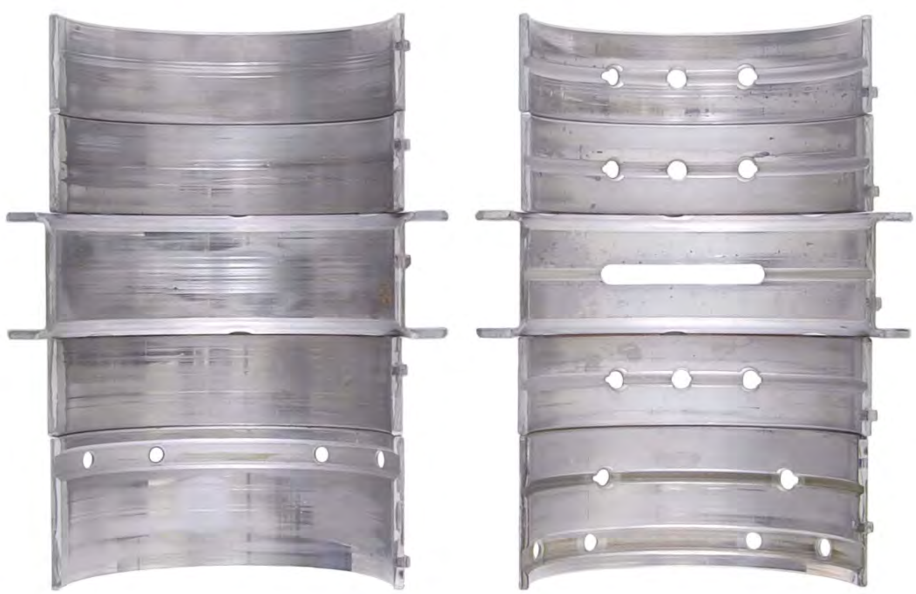
Exhaust and Intake Valve - Worst   Cyl 3

Oil Code:	LO-241026	EOT Date:	4/19/10
Test No.:	LO241026-65T2_WVC	Test Length:	140

Rod Bearings

Oil Code:	LO-241026	EOT Date:	4/19/10
Test No.:	LO241026-65T2_WVC	Test Length:	140

Main Bearings



APPENDIX A3. – MIL-PRF-46167 OEA, REPEATABILITY RUN 3 OF 3

REPEATABILITY EVALUATION 3 OF 3
MIL-PRF-46167D
OEA-30 ARCTIC OIL

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-241026
Arctic Oil – OEA30
Test Fuel: Jet-A w/DCI-4A
Test Number: LO241026-65T3-W-210
Start of Test Date: May 10, 2010
End of Test Date: May 21, 2010
Test Duration: 140 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the statistical repeatability of MIL-PRF-46167D OEA-30 arctic oil when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

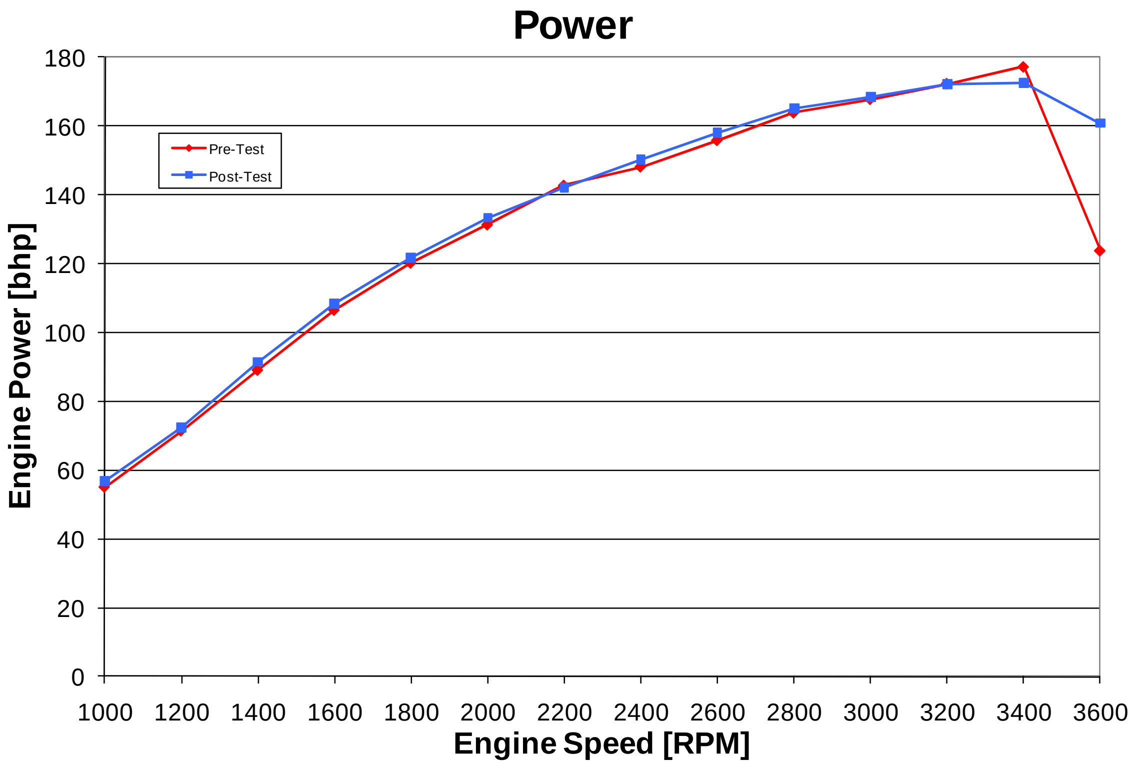
Engine Operating Conditions Summary

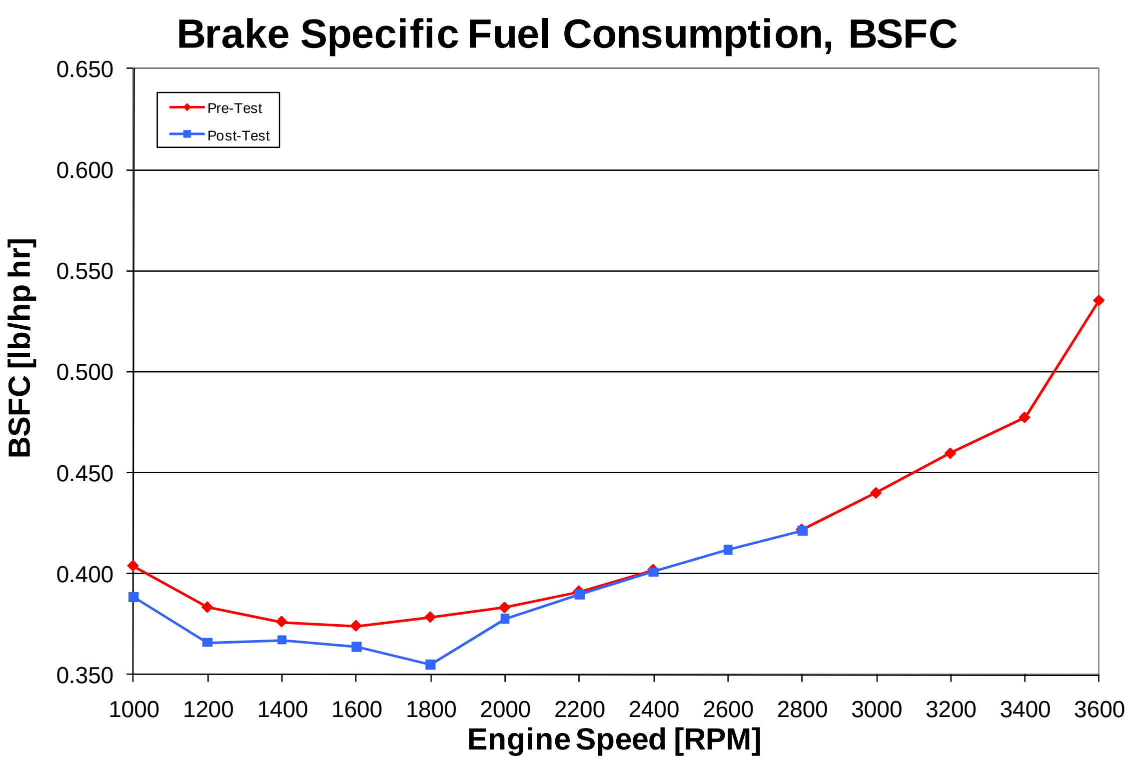
Below is a summary of the engine operating conditions over the test duration. Testing was stopped at 140hrs due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.03	0.73	899.97	2.85
Torque*	ft*lb	256.27	1.75	29.02	1.26
Fuel Flow	lb/hr	77.54	2.19	4.68	0.13
Power*	bhp	165.90	1.12	4.97	0.21
BSFC*	lb/bhp*hr	0.467	0.013	0.941	0.040
Temperatures:					
Coolant In	°F	192.03	0.82	93.03	0.75
Coolant Out	°F	205.00	0.68	99.84	0.62
Oil Sump	°F	260.00	0.37	125.16	1.23
Fuel In	°F	95.02	0.35	94.99	0.35
Intake Air	°F	71.09	2.66	68.03	2.46
Cylinder 1 Exhaust	°F	1114.09	16.49	171.61	4.58
Cylinder 2 Exhaust	°F	1073.72	18.11	159.79	2.92
Cylinder 3 Exhaust	°F	1204.50	12.75	177.38	4.54
Cylinder 4 Exhaust	°F	1083.83	16.72	158.43	3.65
Cylinder 5 Exhaust	°F	1160.56	17.00	177.10	3.63
Cylinder 6 Exhaust	°F	1136.11	17.24	169.45	3.55
Cylinder 7 Exhaust	°F	1094.47	13.12	164.73	3.68
Cylinder 8 Exhaust	°F	1135.14	16.43	163.90	4.15
Pressures:					
Oil Galley	psi	39.28	0.53	39.10	3.19
Ambient Pressure	psiA	14.19	0.05	14.19	0.05
Boost Pressure	psi	4.28	0.06	-0.05	0.05

* Non-corrected Values

Engine Performance Curves



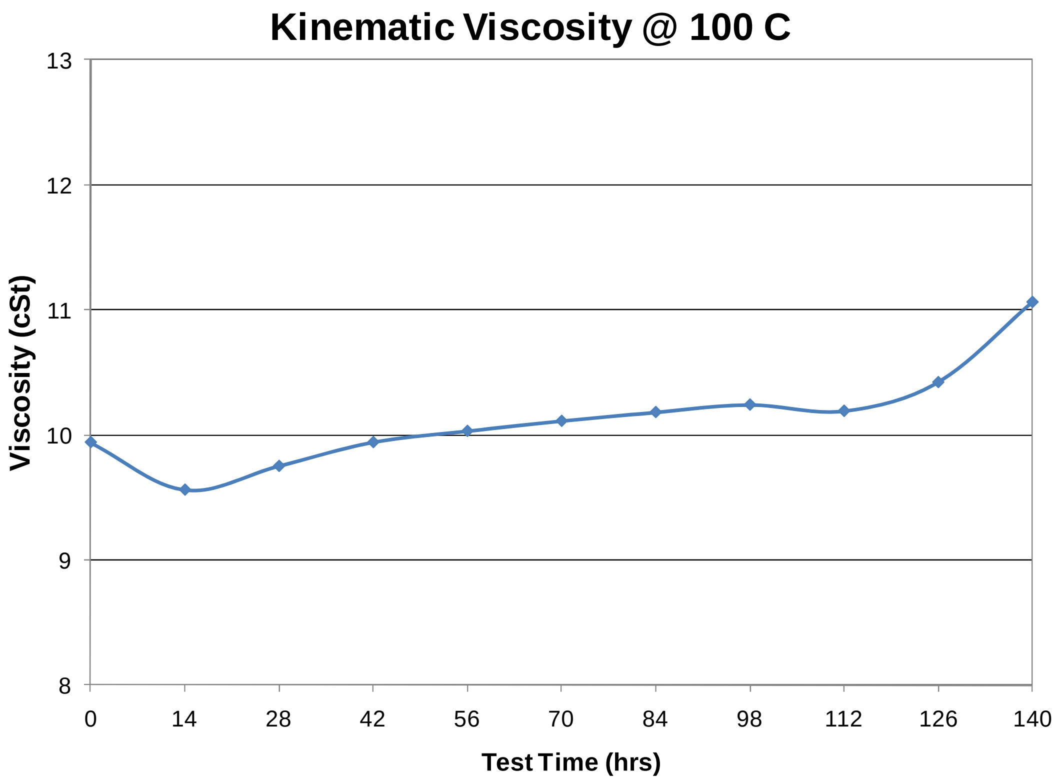


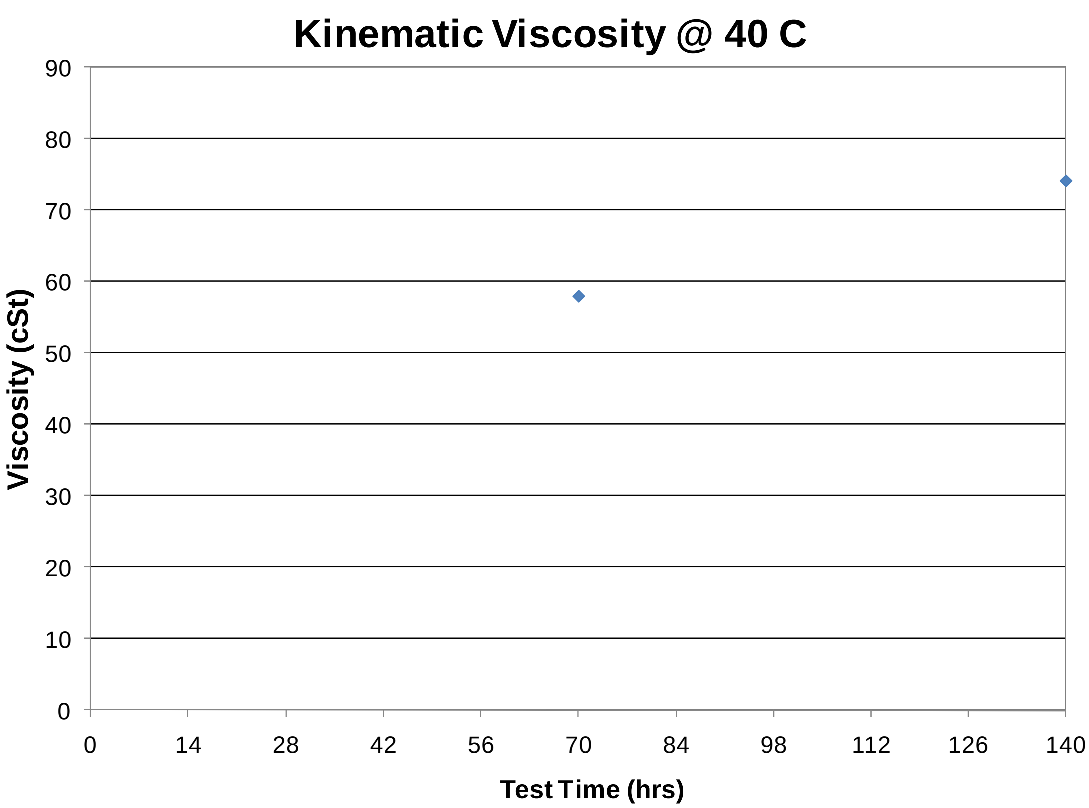
*Note – Breaks in BSFC plot due to invalid values for engine fuel flow during powercurve.

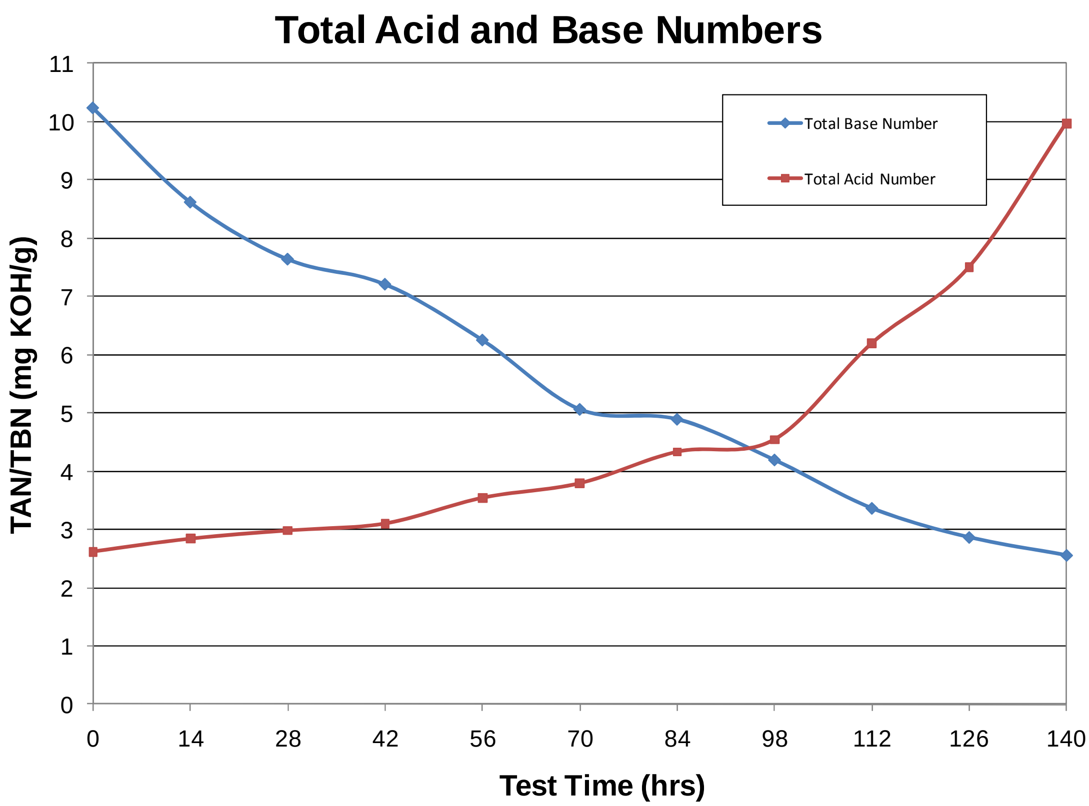
Engine Oil Analysis

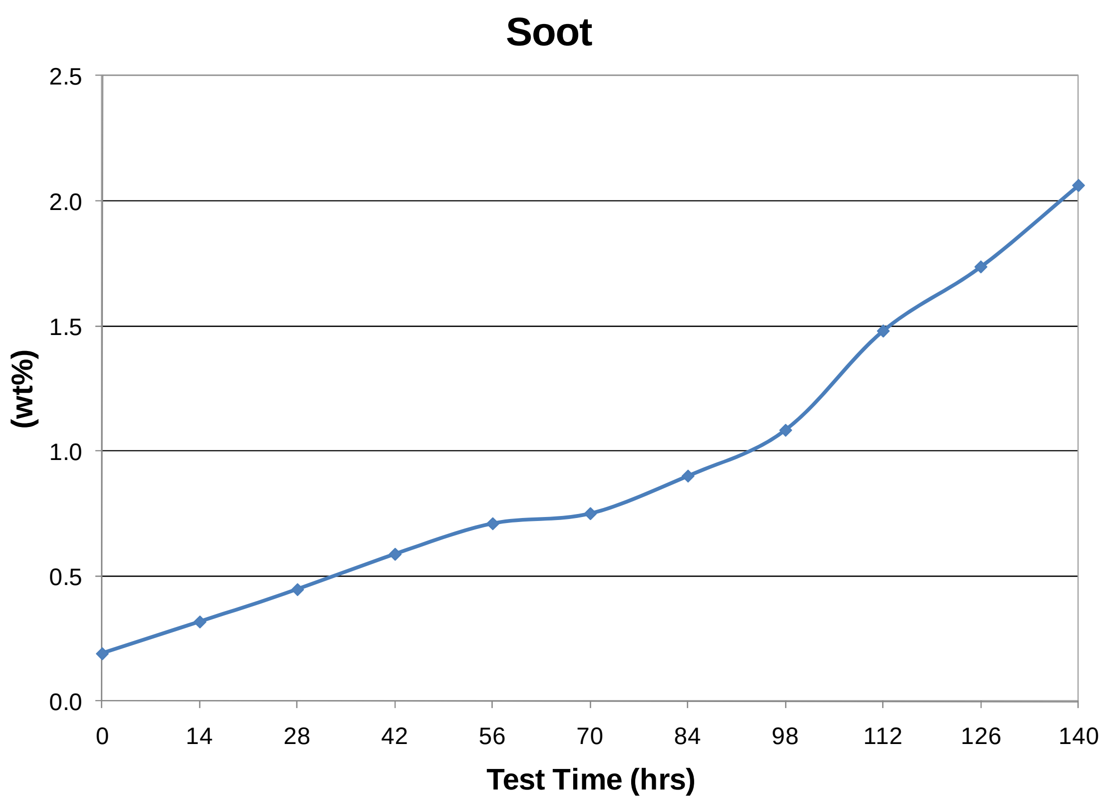
Property	ASTM Test	Test Hours										
		0	14	28	42	56	70	84	98	112	126	140
Density	D4052	0.8485	0.8508	0.853	0.8553	0.8574	0.8598	0.8628	0.8662	0.871	0.8761	0.888
Viscosity @ 100°C (cSt)	D445	9.9	9.6	9.8	9.9	10.0	10.1	10.2	10.2	10.2	10.4	11.1
Viscosity @ 40°C (cSt)	D445						57.9					74.1
Viscosity Index (dyne/cm)	D2270						163.0					139.0
Total Base Number (mg KOH/g)	D4739	10.2	8.6	7.6	7.2	6.3	5.1	4.9	4.2	3.4	2.9	2.6
Total Acid Number (mg KOH/g)	D664	2.6	2.8	3.0	3.1	3.5	3.8	4.3	4.5	6.2	7.5	10.0
Oxidation (Abs./cm)	E168 FTNG	0.0	4.4	9.5	17.9	19.8	25.3	32.4	41.5	56.6	85.7	119.6
Nitration (Abs./cm)	E168 FTNG	0.0	7.0	8.4	8.3	8.9	13.1	20.2	28.9	42.9	57.5	65.9
Soot	Soot	0.2	0.3	0.4	0.6	0.7	0.8	0.9	1.1	1.5	1.7	2.1
Wear Metals (ppm)	D5185											
Al		1	3	3	3	4	3	4	4	4	4	4
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		1	2	<1	2	2	2	3	3	2	2	4
Ca		3460	3627	3667	4002	3734	4112	4240	4347	4557	4694	4709
Cr		<1	1	2	2	3	3	4	4	5	5	6
Cu		<1	15	18	21	25	28	29	32	40	77	177
Fe		2	41	70	96	115	145	171	195	230	268	348
Pb		<1	11	14	15	17	20	26	34	54	130	270
Mg		12	12	13	14	14	15	16	16	17	18	18
Mn		<1	1	2	2	2	2	3	3	4	4	5
Mo		<1	8	12	15	17	19	21	22	23	24	24
Ni		<1	1	3	3	4	4	5	5	6	6	6
P		1249	1160	1115	1158	1119	1185	1231	1222	1277	1303	1314
Si		6	31	37	34	34	34	35	36	35	36	36
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		6	5	<5	7	<5	7	8	5	7	8	7
Sn		<1	8	9	10	10	11	12	13	13	14	16
Zn		1408	1374	1395	1454	1483	1549	1611	1663	1723	1770	1821
K		7	<5	<5	<5	<5	<5	<5	<5	<5	<5	5
Sr		<1	<1	1	<1	1	<1	<1	1	1	1	1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	2

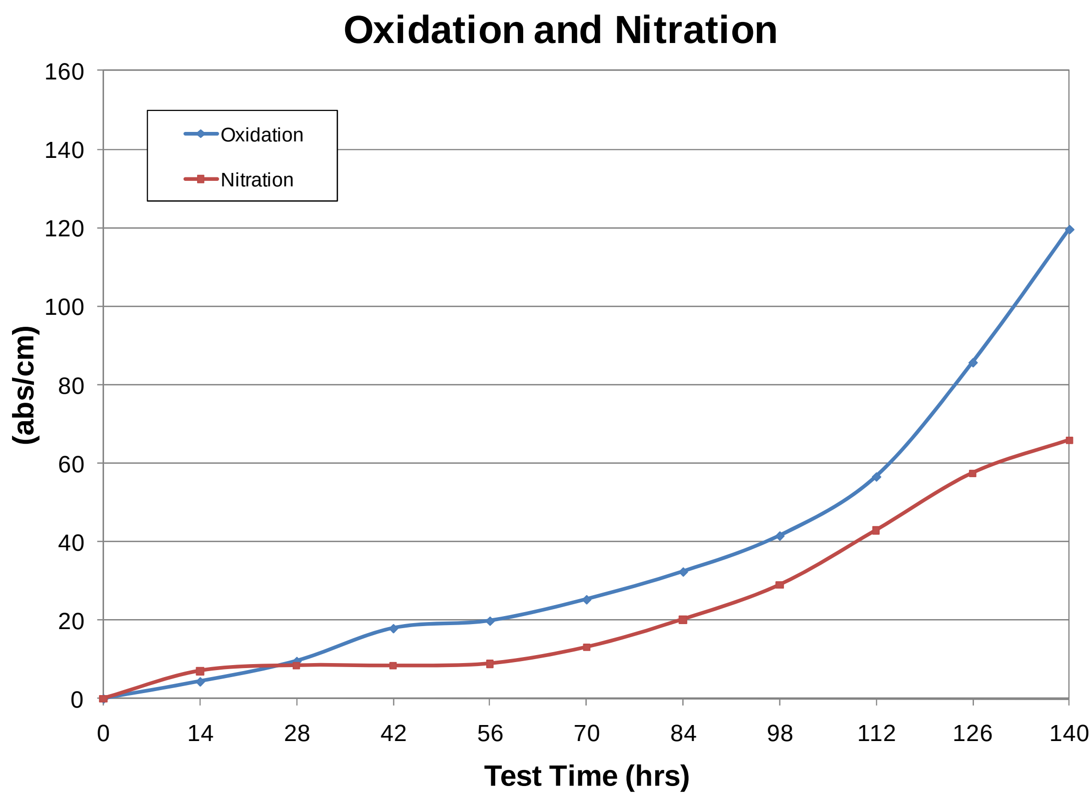
<u>Engine Oil Analysis Trends</u>

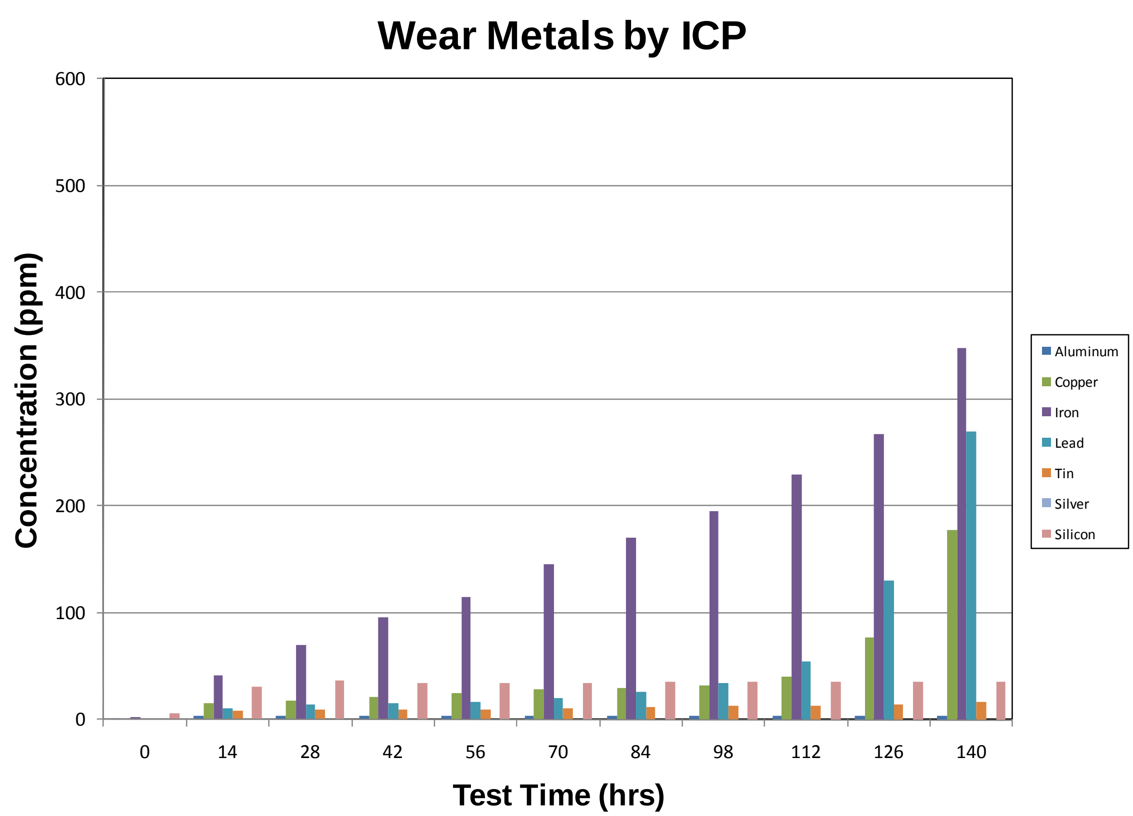





Total Acid and Base Numbers
TAN/TBN (mg KOH/g)
11
10
9
8
7
6
5
4
3
2
1
0
0
14
28
42
56
70
84
98
112
126
140
Test Time (hrs)
Total Base Number
Total Acid Number


Soot
(wt%)
2.5
2.0
1.5
1.0
0.5
0.0
0
14
28
42
56
70
84
98
112
126
140
Test Time (hrs)


Oxidation and Nitration
Oxidation
Nitration
(abs/cm)
160
140
120
100
80
60
40
20
0
0
14
28
42
56
70
84
98
112
126
140
Test Time (hrs)


Wear Metals by ICP
Concentration (ppm)
600
500
400
300
200
100
0
0
14
28
42
56
70
84
98
112
126
140
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

Oil Consumption Data

Average oil consumption per test hour was 0.086 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14-hr	1.66	0.25	1.41	1.41
28-hr	1.6	0.24	1.36	2.77
42-hr	1.62	0.24	1.38	4.15
56-hr	1.22	0.25	0.97	5.12
70-hr	1.16	0.25	0.91	6.03
84-hr	1.37	0.24	1.13	7.16
98-hr	1.41	0.24	1.17	8.33
112-hr	1.36	0.25	1.11	9.44
126-hr	1.64	0.25	1.39	10.83
140-hr		0.25		
	Initial Fill	15.33	**Total Additions**	13.04
	EOT Drain	13.84	**Total Samples**	2.46

(Initial Fill + Additions)	28.37
(EOT Drain + Samples)	16.3
Total Oil Consumption	12.07

Post Test Engine Ratings

Ratings	Clyinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	no	no	no	no	no	no	no	no	--
Ring No.2	no	no	no	no	no	no	no	no	--
Ring No.3	no	no	no	no	no	no	no	no	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	30.75	48.75	62.25	43.75	49.25	43.00	30.00	49.25	44.63
No.2 Groove	8.00	5.00	15.75	2.25	3.25	7.00	2.75	10.00	6.75
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	55.25	41.25	43.00	53.00	58.75	42.75	42.25	43.00	47.41
No.2 Land	15.75	18.50	24.75	10.00	17.00	24.00	19.00	20.25	18.66
No.3 Land	0.00	0.50	0.00	0.00	1.25	1.25	0.00	0.00	0.38
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	3.00	2.56	2.66	2.56	3.31	2.45	3.07	1.70	2.66
No.3 Groove	2.28	2.28	2.45	1.08	1.00	2.56	1.02	1.37	1.76
No.1 Land	0.71	0.33	0.48	0.04	0.00	0.02	0.00	0.00	0.20
No.2 Land	1.92	1.94	1.21	1.52	1.44	0.81	0.98	0.48	1.29
No.3 Land	2.83	2.53	2.66	1.65	1.88	1.88	1.60	1.84	2.11
Upper Skirt	1.57	1.65	1.57	0.27	0.20	0.46	0.20	0.55	0.81
Under Crown	4.24	2.95	4.00	2.56	1.80	3.46	2.30	5.43	3.34
Front Pin Bore	1.21	1.12	1.68	1.30	0.26	1.30	1.30	1.54	1.21
Rear Pin Bore	1.93	1.70	1.02	0.26	1.30	1.24	1.70	2.10	1.41
Total, Demerits	129.44	131.06	163.48	120.24	140.69	132.18	106.17	137.51	132.60
Miscellanous									
Top Groove Fill, %	22	52	52	40	47	43	29	42	40.88
Intermediate Groove Fill, %	4	2	3	0	0	2	0	1	1.50
Top Land Heavy Carbon, %	45	28	33	40	45	25	23	24	32.88
Top Lan Flaked Carbon, %	2	0	1	0	0	0	0	0	0.38
Valve Tulip Deposits, Merits									
Exahust	9.0	9.0	9.6	9.0	9.0	9.1	9.0	9.0	9.09
Intake	6.7	6.8	6.3	6.5	6.7	7.3	6.7	6.5	6.69

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0547	4.0554	4.0550	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0000	0.0015	0.0006	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0001	0.0009	0.0005	
Piston Skirt Diameter	4.0498	4.0501	4.0500	
Piston Skirt to Cylinder Bore Clearance	0.0047	0.0054	0.0050	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.015	0.018	0.016	
Second Ring	0.034	0.038	0.036	
Oil Control Ring	0.014	0.017	0.015	
Ring To Groove Clearance				
Second Ring	0.0015	0.0015	0.0015	0.0015"-0.003"
Oil Control Ring	0.0020	0.0020	0.0020	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2204	1.2204	1.2204	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2210	1.2210	1.2210	1.2207"-1.2212"
Piston Pin Clearance	0.0006	0.0006	0.0006	0.0003"-0.0012"
Piston Pin Diameter	1.2204	1.2204	1.2204	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2213	1.2215	1.2214	1.2207"-1.2212"
Piston Pin Clearance	0.0009	0.0011	0.0010	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0020	0.0025	0.0023	0.0017"-0.0039"
Main Bearing to Journa	0.0030	0.0030	0.0030	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.006	0.004-0.010"
Rod Side Clearance	0.019	0.020	0.019	0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0550	4.0549		0.0001
	Middle	4.0547	4.0540	4.0547	0.0007
	Bottom	4.0547	4.0543		0.0004
	Taper	0.0003	0.0009		
2	Top	4.0550	4.0549		0.0001
	Middle	4.0548	4.0540	4.0547	0.0008
	Bottom	4.0545	4.0543		0.0002
	Taper	0.0005	0.0009		
3	Top	4.0552	4.0546		0.0006
	Middle	4.0550	4.0540	4.0554	0.0010
	Bottom	4.0558	4.0543		0.0015
	Taper	0.0008	0.0006		
4	Top	4.0550	4.0548		0.0002
	Middle	4.0548	4.0540	4.0547	0.0008
	Bottom	4.0546	4.0543		0.0003
	Taper	0.0004	0.0008		
5	Top	4.0550	4.0546		0.0004
	Middle	4.0548	4.0540	4.0548	0.0008
	Bottom	4.0548	4.0542		0.0006
	Taper	0.0002	0.0006		
6	Top	4.0550	4.0546		0.0004
	Middle	4.0548	4.0540	4.0548	0.0008
	Bottom	4.0547	4.0543		0.0004
	Taper	0.0003	0.0006		
7	Top	4.0554	4.0554		0.0000
	Middle	4.0553	4.0545	4.0553	0.0008
	Bottom	4.0553	4.0547		0.0006
	Taper	0.0001	0.0009		
8	Top	4.0554	4.0552		0.0002
	Middle	4.0555	4.0545	4.0554	0.0010
	Bottom	4.0553	4.0548		0.0005
	Taper	0.0002	0.0007		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0553	4.0546		0.0007
	Middle	4.0548	4.0541	4.0548	0.0007
	Bottom	4.0547	4.0546		0.0001
	Taper	0.0006	0.0005		
2	Top	4.0554	4.0546		0.0008
	Middle	4.0550	4.0541	4.0549	0.0009
	Bottom	4.0547	4.0546		0.0001
	Taper	0.0007	0.0005		
3	Top	4.0553	4.0544		0.0009
	Middle	4.0549	4.0541	4.0548	0.0008
	Bottom	4.0546	4.0545		0.0001
	Taper	0.0007	0.0004		
4	Top	4.0552	4.0545		0.0007
	Middle	4.0550	4.0541	4.0548	0.0009
	Bottom	4.0546	4.0546		0.0000
	Taper	0.0006	0.0005		
5	Top	4.0552	4.0542		0.0010
	Middle	4.0549	4.0540	4.0548	0.0009
	Bottom	4.0546	4.0545		0.0001
	Taper	0.0006	0.0005		
6	Top	4.0553	4.0543		0.0010
	Middle	4.0549	4.0540	4.0548	0.0009
	Bottom	4.0546	4.0545		0.0001
	Taper	0.0007	0.0005		
7	Top	4.0557	4.0552		0.0005
	Middle	4.0555	4.0548	4.0554	0.0007
	Bottom	4.0552	4.0551		0.0001
	Taper	0.0005	0.0004		
8	Top	4.0556	4.0553		0.0003
	Middle	4.0553	4.0548	4.0552	0.0005
	Bottom	4.0551	4.0554		0.0003
	Taper	0.0005	0.0006		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0003	0.0003	
	Middle	0.0001	0.0001	0.0000
	Bottom	0.0000	0.0003	
2	Top	0.0004	0.0003	
	Middle	0.0002	0.0001	0.0002
	Bottom	0.0002	0.0003	
3	Top	0.0001	0.0002	
	Middle	0.0001	0.0001	0.0006
	Bottom	0.0012	0.0002	
4	Top	0.0002	0.0003	
	Middle	0.0002	0.0001	0.0001
	Bottom	0.0000	0.0003	
5	Top	0.0002	0.0004	
	Middle	0.0001	0.0000	0.0002
	Bottom	0.0002	0.0003	
6	Top	0.0003	0.0003	
	Middle	0.0001	0.0000	0.0001
	Bottom	0.0001	0.0002	
7	Top	0.0003	0.0002	
	Middle	0.0002	0.0003	0.0002
	Bottom	0.0001	0.0004	
8	Top	0.0002	0.0001	
	Middle	0.0002	0.0003	0.0002
	Bottom	0.0002	0.0006	
Avgerage All Cylinders	Top	0.0003	0.0003	
	Middle	0.0001	0.0001	
	Bottom	0.0003	0.0003	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3431	0.3460	0.0029	0.3738	0.3765	0.0027
2	0.3431	0.3466	0.0035	0.3737	0.3767	0.0030
3	0.3430	0.3460	0.0030	0.3737	0.3756	0.0019
4	0.3430	0.3463	0.0033	0.3736	0.3767	0.0031
5	0.3436	0.3460	0.0024	0.3738	0.3756	0.0018
6	0.3431	0.3463	0.0032	0.3738	0.3767	0.0029
7	0.3436	0.3460	0.0024	0.3738	0.3756	0.0018
8	0.3430	0.3463	0.0033	0.3737	0.3767	0.0030

Maximum	0.0035	Maximum	0.0031
Average	0.0030	Average	0.0025

Valve Stem Measurement Changes, inches

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3412	0.3413	-0.0001	0.3711	0.3711	0.0000
2	0.3413	0.3412	0.0001	0.3712	0.3712	0.0000
3	0.3412	0.3411	0.0001	0.3711	0.3711	0.0000
4	0.3412	0.3411	0.0001	0.3712	0.3713	-0.0001
5	0.3415	0.3413	0.0002	0.3711	0.3713	-0.0002
6	0.3412	0.3412	0.0000	0.3711	0.3712	-0.0001
7	0.3422	0.3413	0.0009	0.3711	0.3711	0.0000
8	0.3413	0.3412	0.0001	0.3712	0.3713	-0.0001

Maximum	0.0009	Maximum	0.0000
Average	0.0002	Average	-0.0001

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance Intake			Stem Guide Clearance Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0019	0.0047	0.0028	0.0027	0.0054	0.0027
2	0.0018	0.0054	0.0036	0.0025	0.0055	0.0030
3	0.0018	0.0049	0.0031	0.0026	0.0045	0.0019
4	0.0018	0.0052	0.0034	0.0024	0.0054	0.0030
5	0.0021	0.0047	0.0026	0.0027	0.0043	0.0016
6	0.0019	0.0051	0.0032	0.0027	0.0055	0.0028
7	0.0014	0.0047	0.0033	0.0027	0.0045	0.0018
8	0.0017	0.0051	0.0034	0.0025	0.0054	0.0029

Maximum	0.0036
Average	0.0032

Maximum	0.0030
Average	0.0025

Valve Recession Measurement Changes, inches

	Valve Recession Intake			Valve Recession Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.027	0.042	0.015	0.029	0.033	0.004
2	0.027	0.044	0.017	0.025	0.026	0.001
3	0.026	0.034	0.008	0.025	0.026	0.000
4	0.025	0.042	0.017	0.027	0.027	0.000
5	0.026	0.046	0.020	0.026	0.055	0.029
6	0.026	0.039	0.013	0.026	0.025	-0.001
7	0.028	0.039	0.011	0.027	0.041	0.014
8	0.024	0.042	0.018	0.026	0.029	0.003

Maximum	0.020
Average	0.015

Maximum	0.029
Average	0.006

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	1.73
2	1.61
3	1.57
4	1.81
5	3.33
6	1.39
7	1.67
8	1.82
9	2.05
10	1.69
11	1.74
12	1.59
13	2.84
14	1.54
15	2.09
16	2.17

Maximum	3.33
Average	1.92

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0547	4.0498	0.0049
	2	4.0547	4.0500	0.0047
	3	4.0554	4.0500	0.0054
	4	4.0547	4.0500	0.0047
	5	4.0548	4.0500	0.0048
	6	4.0548	4.0501	0.0047
	7	4.0553	4.0500	0.0053
	8	4.0554	4.0501	0.0053
Post - Test	1	4.0548	4.0497	0.0051
	2	4.0549	4.0500	0.0049
	3	4.0548	4.0498	0.0050
	4	4.0548	4.0498	0.0050
	5	4.0548	4.0497	0.0051
	6	4.0548	4.0501	0.0047
	7	4.0554	4.0499	0.0055
	8	4.0552	4.0497	0.0055

Top and Second Ring Radial Wear, inches

Top Ring				
Cylinder	**Position**	**Before**	**After**	**Delta**
1	1	0.17860	0.17860	0.00000
	2	0.17845	0.17805	0.00040
	3	0.17865	0.17845	0.00020
	4	0.18050	0.18040	0.00010
	5	0.17900	0.17900	0.00000
2	1	0.17830	0.17795	0.00035
	2	0.17820	0.17795	0.00025
	3	0.17835	0.17800	0.00035
	4	0.17870	0.17845	0.00025
	5	0.17830	0.17805	0.00025
3	1	0.18135	0.18105	0.00030
	2	0.17745	0.17720	0.00025
	3	0.17815	0.17770	0.00045
	4	0.18055	0.18035	0.00020
	5	0.18185	0.18140	0.00045
4	1	0.18210	0.18175	0.00035
	2	0.18050	0.18015	0.00035
	3	0.18275	0.18255	0.00020
	4	0.18195	0.18160	0.00035
	5	0.18095	0.18045	0.00050
5	1	0.17920	0.17850	0.00070
	2	0.17805	0.17760	0.00045
	3	0.18005	0.17965	0.00040
	4	0.17805	0.17770	0.00035
	5	0.17845	0.17820	0.00025
6	1	0.18075	0.18035	0.00040
	2	0.17915	0.17900	0.00015
	3	0.17700	0.17680	0.00020
	4	0.17840	0.17790	0.00050
	5	0.17995	0.17995	0.00000
7	1	0.17895	0.17870	0.00025
	2	0.17925	0.17885	0.00040
	3	0.17775	0.17740	0.00035
	4	0.17865	0.17850	0.00015
	5	0.17975	0.17955	0.00020
8	1	0.17900	0.17875	0.00025
	2	0.17840	0.17835	0.00005
	3	0.17835	0.17805	0.00030
	4	0.17830	0.17820	0.00010
	5	0.17960	0.17945	0.00015

Maximum	0.00070
Average	0.00028

Second Ring				
Cylinder	**Position**	**Before**	**After**	**Delta**
1	1	0.16270	0.16210	0.00060
	2	0.16225	0.16190	0.00035
	3	0.16145	0.16090	0.00055
	4	0.16175	0.16135	0.00040
	5	0.16270	0.16215	0.00055
2	1	0.16180	0.16140	0.00040
	2	0.16155	0.16090	0.00065
	3	0.16155	0.16080	0.00075
	4	0.16170	0.16110	0.00060
	5	0.16210	0.16155	0.00055
3	1	0.16245	0.16170	0.00075
	2	0.16135	0.16095	0.00040
	3	0.16140	0.16045	0.00095
	4	0.16160	0.16115	0.00045
	5	0.16245	0.16165	0.00080
4	1	0.16235	0.16160	0.00075
	2	0.16180	0.16160	0.00020
	3	0.16085	0.16030	0.00055
	4	0.16185	0.16120	0.00065
	5	0.16265	0.16190	0.00075
5	1	0.16225	0.16125	0.00100
	2	0.16150	0.16080	0.00070
	3	0.16140	0.16035	0.00105
	4	0.16100	0.16065	0.00035
	5	0.16215	0.16120	0.00095
6	1	0.16250	0.16215	0.00035
	2	0.16215	0.16160	0.00055
	3	0.16170	0.16125	0.00045
	4	0.16210	0.16125	0.00085
	5	0.16300	0.16225	0.00075
7	1	0.16305	0.16270	0.00035
	2	0.16250	0.16200	0.00050
	3	0.16220	0.16150	0.00070
	4	0.16195	0.16155	0.00040
	5	0.16260	0.16205	0.00055
8	1	0.16200	0.16145	0.00055
	2	0.16125	0.16085	0.00040
	3	0.16105	0.16055	0.00050
	4	0.16120	0.16080	0.00040
	5	0.16185	0.16130	0.00055

Maximum	0.00105
Average	0.00059

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.016	0.020	0.004
	2	0.035	0.044	0.009
	3	0.015	0.015	0.000
2	1	0.015	0.018	0.003
	2	0.035	0.043	0.008
	3	0.015	0.015	0.000
3	1	0.015	0.017	0.002
	2	0.035	0.043	0.008
	3	0.014	0.015	0.001
4	1	0.015	0.016	0.001
	2	0.034	0.040	0.006
	3	0.014	0.015	0.001
5	1	0.015	0.017	0.002
	2	0.034	0.040	0.006
	3	0.014	0.014	0.000
6	1	0.015	0.020	0.005
	2	0.036	0.043	0.007
	3	0.014	0.016	0.002
7	1	0.018	0.020	0.002
	2	0.038	0.042	0.004
	3	0.016	0.016	0.000
8	1	0.017	0.021	0.004
	2	0.037	0.045	0.008
	3	0.017	0.020	0.003

Ring No. 1 max increase	0.005
Ring No. 2 max increase	0.009
Ring No. 3 max increase	0.003

Ring No. 1 avg increase	0.003
Ring No. 2 avg increase	0.007
Ring No. 3 avg increase	0.001

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.7072	22.6560	0.0512
	2	17.2216	17.1976	0.0240
	3	14.8202	14.7968	0.0234
2	1	22.5399	22.4825	0.0574
	2	17.0538	17.0277	0.0261
	3	14.9674	14.9490	0.0184
3	1	22.6727	22.6082	0.0645
	2	17.2222	17.1944	0.0278
	3	15.0019	14.9851	0.0168
4	1	22.7293	22.6773	0.0520
	2	17.2586	17.2360	0.0226
	3	14.9610	14.9448	0.0162
5	1	22.6749	22.5838	0.0911
	2	17.1785	17.1503	0.0282
	3	15.1435	15.1245	0.0190
6	1	22.5394	22.4780	0.0614
	2	17.2710	17.2463	0.0247
	3	15.0737	15.0577	0.0160
7	1	22.6173	22.5535	0.0638
	2	17.1601	17.1341	0.0260
	3	15.0838	15.0629	0.0209
8	1	22.6157	22.5682	0.0475
	2	17.1439	17.1247	0.0192
	3	14.9740	14.9576	0.0164

Ring No. 1 max decrease	0.0911
Ring No. 2 max decrease	0.0282
Ring No. 3 max decrease	0.0234

Ring No. 1 avg decrease	0.0611
Ring No. 2 avg decrease	0.0248
Ring No. 3 avg decrease	0.0184

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.8104	27.7828	0.0276
	Bottom	27.7274	27.6653	0.0621
2	Top	27.7649	27.7526	0.0123
	Bottom	27.7539	27.7176	0.0363
3	Top	27.7560	27.7382	0.0178
	Bottom	27.7947	27.7557	0.0390
4	Top	27.7489	27.7356	0.0133
	Bottom	27.7955	27.7730	0.0225
5	Top	27.6765	27.6590	0.0175
	Bottom	27.7104	27.6745	0.0359
6	Top	27.6573	27.6573	0.0000
	Bottom	27.8179	27.8179	0.0000
7	Top	27.7489	27.7156	0.0333
	Bottom	27.8032	27.7700	0.0332
8	Top	27.7536	27.7373	0.0163
	Bottom	27.7833	27.7192	0.0641

Maximum	0.0641
Average	0.0270

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.3233	48.3013	0.0220
	Bottom	52.7318	52.7166	0.0152
2	Top	48.3767	48.3613	0.0154
	Bottom	52.6795	52.6473	0.0322
3	Top	94.1574	92.0871	2.0703
	Bottom	99.6942	99.0367	0.6575
4	Top	48.3902	48.3752	0.0150
	Bottom	52.8281	52.8014	0.0267
5	Top	69.2739	69.1935	0.0804
	Bottom	73.4152	73.3474	0.0678

Maximum	2.0703
Average	0.3002

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 14712659**
Test condition :	

PUMP RPM	***Description***	***Spec.***	***Before***	***After***	***Change***
1000	Transfer pump psi.	60-62 psi	62	62	0
	Return Fuel	225-375 cc	310	342	32
350	Low Idle	12-16 cc	14	13.5	0.5
	Housing psi.	8-12 psi	8	9	1
	Advance	3.5 deg. min	6.45	5.89	0.56
	Cold Advance Solenoid	0-1 psi.	0.5	0.5	0
750	Shut-Off	4 cc max.	0	0	0
900	Fuel Delivery	66.5 - 69.5cc	68	68	0
1600	WOT Fuel delivery	59.5 min.	64	63	1
	WOT Advance	2.5 - 3.5 deg.	3.07	3.29	0.22
	Face Cam Fuel delivery	21.5 - 23.5	22	22	0
	Face Cam Advance	5.25 - 7.25 deg.	6.38	6.63	0.25
	Low Idle	11 - 12 deg.	11.25	11.11	0.14
1825	Fuel Delivery	33 cc min.	38	46	8
1950	High Idle	15 cc max.	2	14	12
	Transfer pump psi.	125 psi max.	108	98	10
200	WOT Fuel Delivery	58 cc min.	62	62	0
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	51	51	0
	Transfer pump psi.	16 psi min.	27	27	0
	Housing psi.	0 -12 psi	8	7	1
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5	-0.5	0
	Fluid Temp. Deg. C				
	Date		3/12/2010	6/1/2010	

*Pump calibration data to be used for reference only

Photographs

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO241026	**EOT Date:**	05/21/10
Test No.:	LO241026-65T3-W-210	**Test Length:**	140

Piston Skirt Thrust - Best CYL 7

Piston Skirt Anti-thrust - Best CYL 7

Oil Code:	LO241026	**EOT Date:**	05/21/10
Test No.:	LO241026-65T3-W-210	**Test Length:**	140

Piston Skirt Thrust - Worst CYL 3

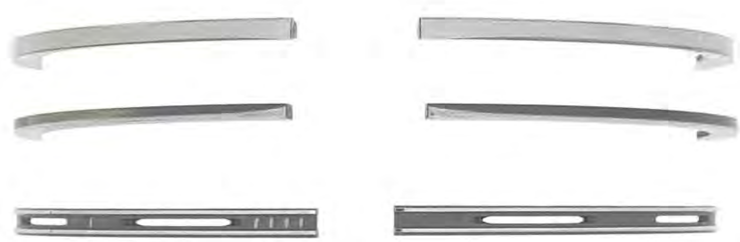
Piston Skirt Anti-thrust - Worst CYL 3

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO241026	EOT Date:	05/21/10
Test No.:	LO241026-65T3-W-210	Test Length:	140

Piston Rings - Best CYL 4

Piston Rings - Worst CYL 5



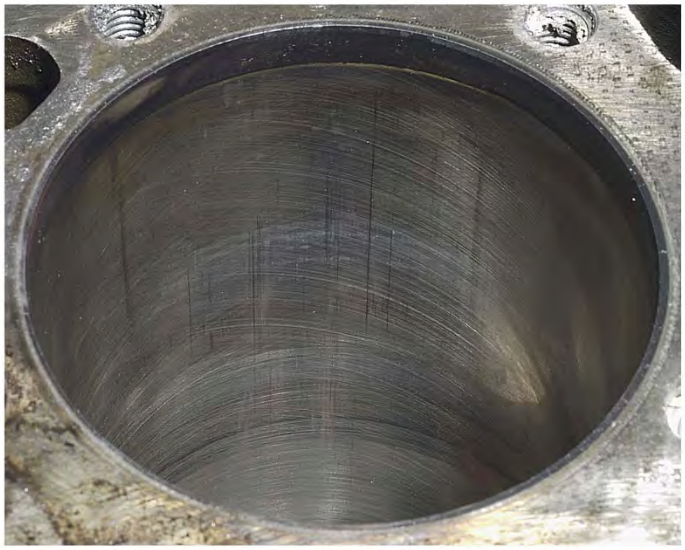
Oil Code:	LO241026	**EOT Date:**	05/21/10
Test No.:	LO241026-65T3-W-210	**Test Length:**	140

Piston Undercrown - Best CYL 7

Piston Undercrown - Worst CYL 3

Oil Code:	LO241026	**EOT Date:**	05/21/10
Test No.:	LO241026-65T3-W-210	**Test Length:**	140

Engine Block Cylinder Bore - Best CYL 7



Engine Block Cylinder Bore - Worst CYL 8

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO241026	**EOT Date:**	05/21/10
Test No.:	LO241026-65T3-W-210	**Test Length:**	140

Exhaust and Intake Valve - Best CYL 6

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO241026	**EOT Date:**	05/21/10
Test No.:	LO241026-65T3-W-210	**Test Length:**	140

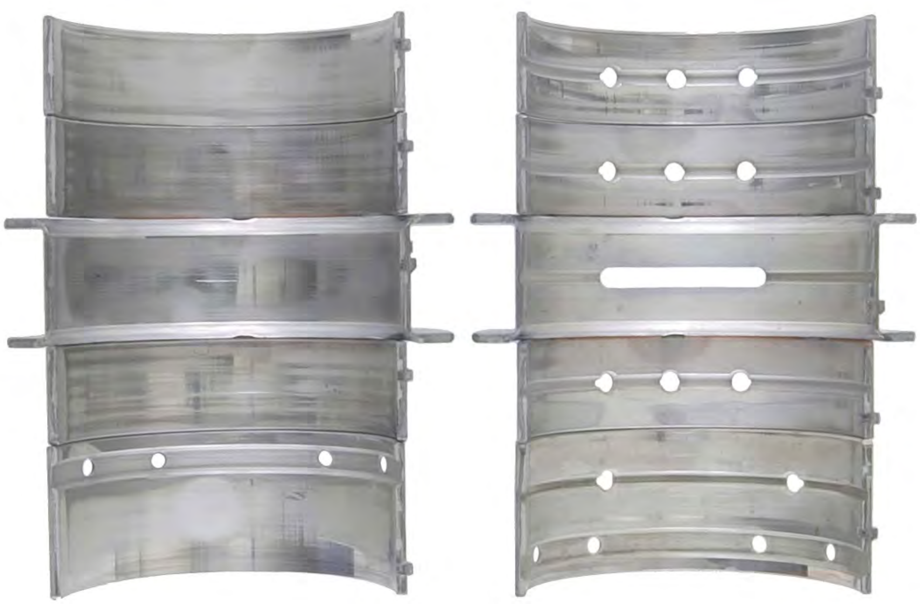
Exhaust and Intake Valve - Worst CYL 8

Oil Code:	LO241026	EOT Date:	05/21/10
Test No.:	LO241026-65T3-W-210	Test Length:	140

Rod Bearings

Oil Code:	LO241026	EOT Date:	05/21/10
Test No.:	LO241026-65T3-W-210	Test Length:	140

Main Bearings



APPENDIX B1. – EVALUATION OF MIL-PRF-2104G IN THE 6.5L(T) HIGH TEMPERATURE OIL ENDURANCE TEST

EVALUATION OF SCPL CANDIDATE LO-246362 MIL-PRF-2104G Baseline

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-246362
Test Fuel: Jet-A w/DCI-4A
Test Number: LO246362-65T1-W-210
Start of Test Date: August 16, 2010
End of Test Date: August 23, 2010
Test Duration: 84 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-246362 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

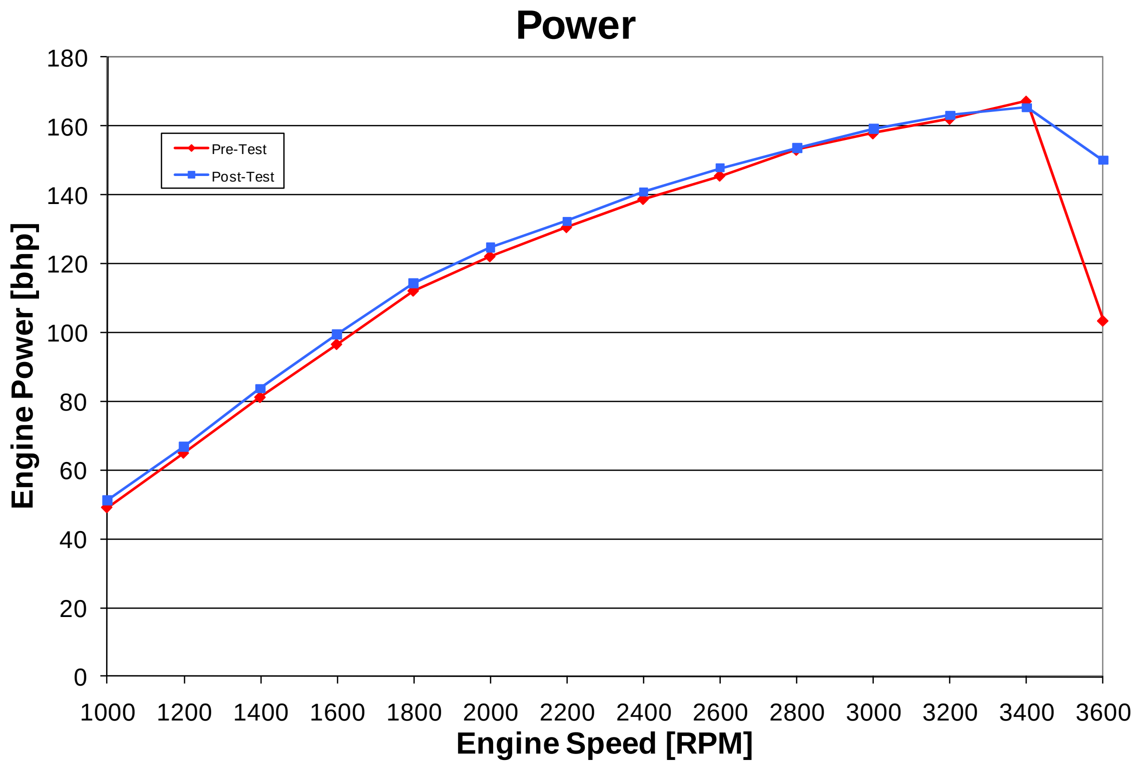
Engine Operating Conditions Summary

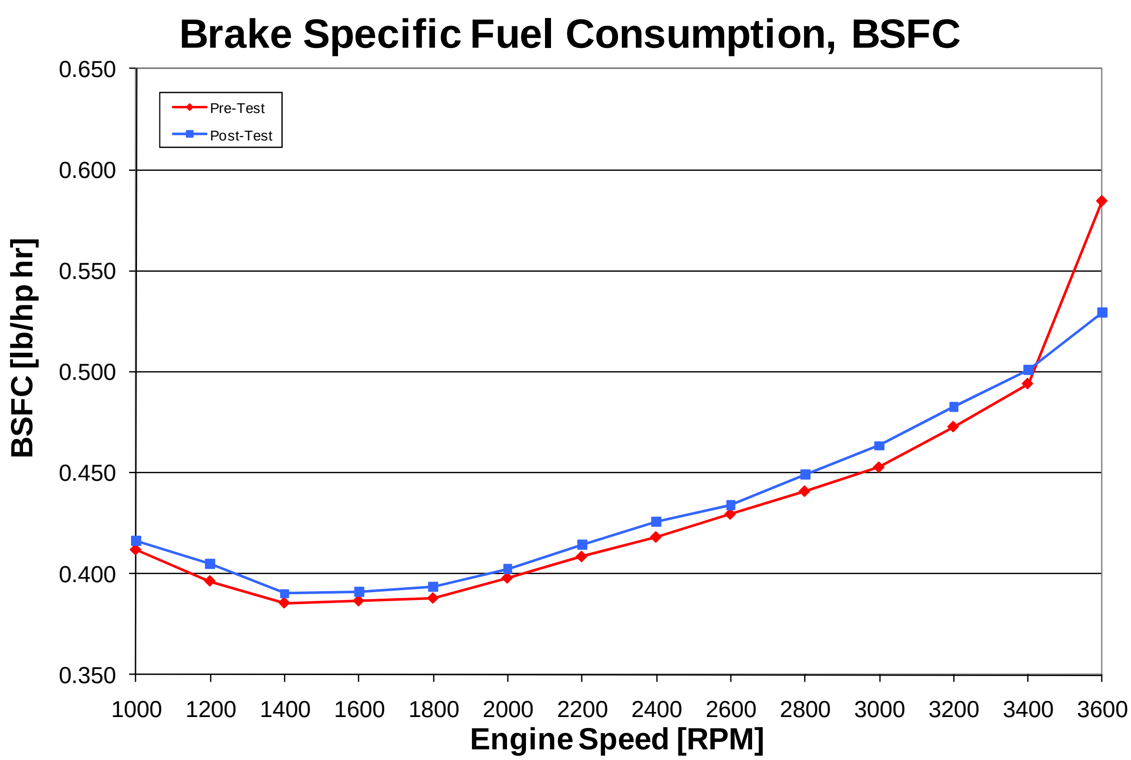
Below is a summary of the engine operating conditions over the test duration. Testing was stopped at 86hrs due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.02	0.79	900.05	1.16
Torque*	ft*lb	255.39	1.91	41.59	15.97
Fuel Flow	lb/hr	80.30	0.86	5.70	0.94
Power*	bhp	165.33	1.22	7.12	2.74
BSFC*	lb/bhp*hr	0.486	0.006	0.855	0.202
Temperatures:					
Coolant In	°F	190.84	0.67	91.93	0.86
Coolant Out	°F	204.99	0.61	100.03	0.49
Oil Sump	°F	260.01	1.15	126.04	1.69
Fuel In	°F	95.27	0.88	94.99	0.31
Intake Air	°F	68.99	1.87	63.37	2.08
Cylinder 1 Exhaust	°F	1129.50	16.49	210.86	28.33
Cylinder 2 Exhaust	°F	1198.55	9.85	211.04	27.52
Cylinder 3 Exhaust	°F	1196.31	10.84	215.08	25.60
Cylinder 4 Exhaust	°F	1119.81	12.52	204.52	24.65
Cylinder 5 Exhaust	°F	1136.14	9.87	210.78	23.93
Cylinder 6 Exhaust	°F	1142.53	13.50	207.49	26.13
Cylinder 7 Exhaust	°F	1123.31	11.20	201.06	23.10
Cylinder 8 Exhaust	°F	1152.38	9.48	204.46	24.43
Pressures:					
Oil Galley	psi	41.85	0.91	51.67	1.21
Ambient Pressure	psiA	14.23	0.04	14.22	0.04
Boost Pressure	psi	4.60	0.06	-0.28	0.05

* Non-corrected Values

Engine Performance Curves

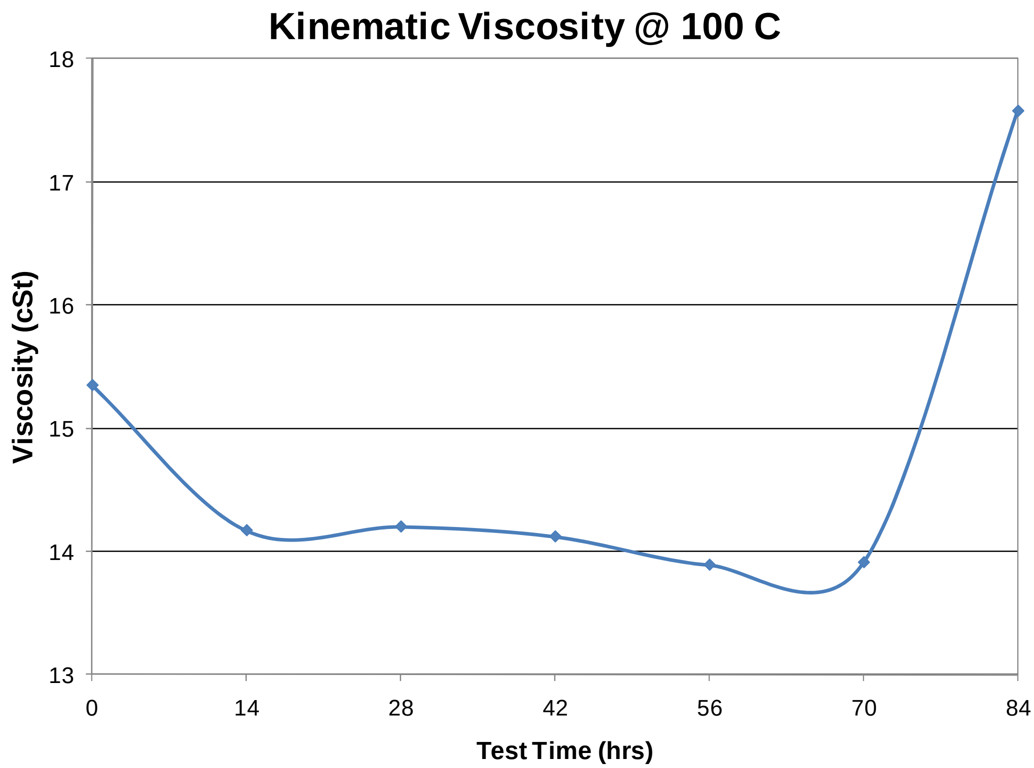


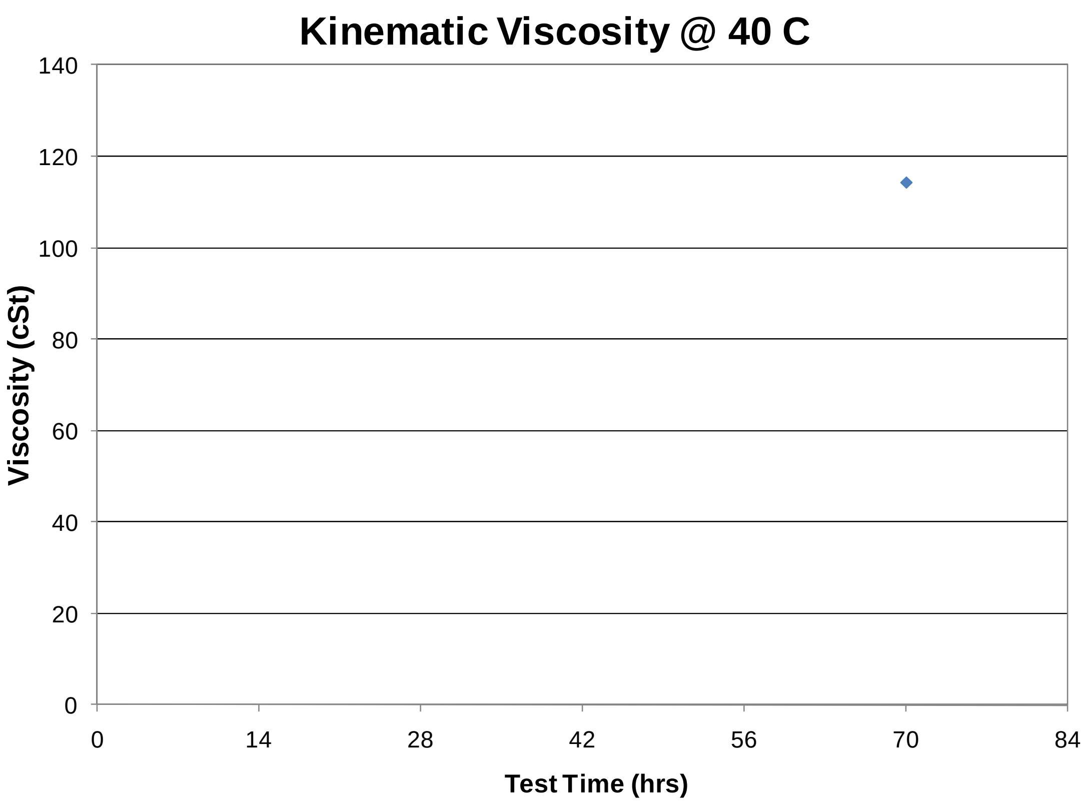


Engine Oil Analysis

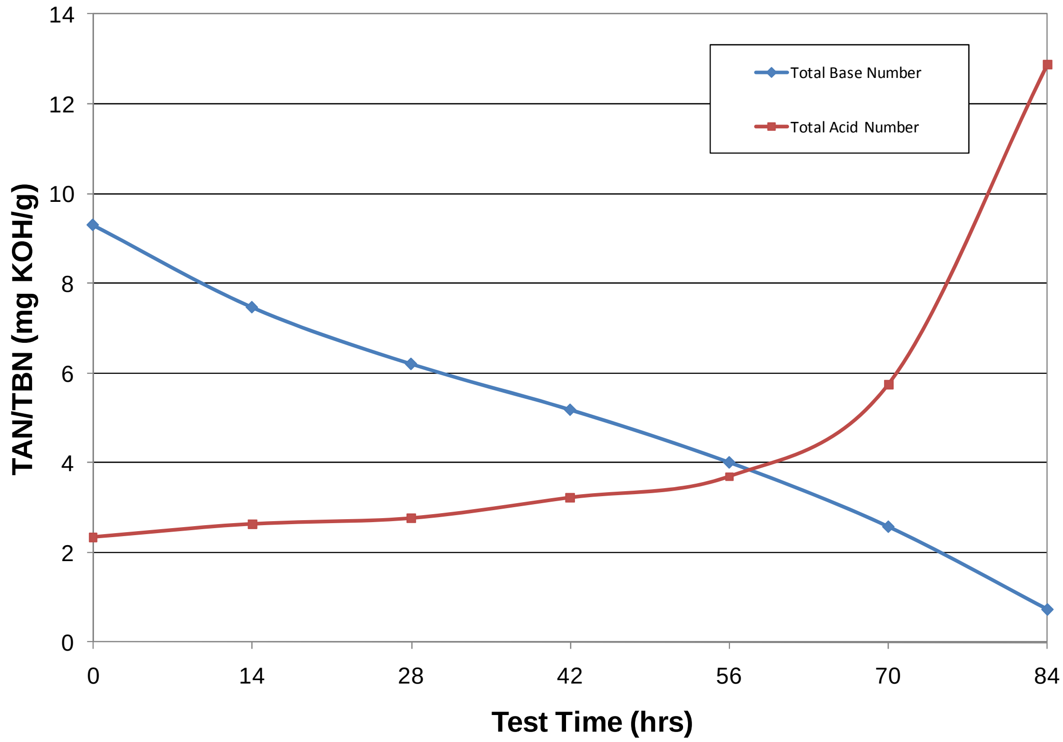
Property	ASTM Test	Test Hours						
		0	14	28	42	56	70	84
Density	D4052	0.8724	0.8748	0.8772	0.8799	0.8834	0.8911	0.9161
Viscosity @ 100°C (cSt)	**D445**	15.4	14.2	14.2	14.1	13.9	13.9	17.6
Viscosity @ 40°C (cSt)	**D445**						114.3	
Viscosity Index (dyne/cm)	**D2270**						121.0	
Total Base Number (mg KOH/g)	**D4739**	9.3	7.5	6.2	5.2	4.0	2.6	0.7
Total Acid Number (mg KOH/g)	**D664**	2.3	2.6	2.8	3.2	3.7	5.7	12.9
Oxidation (Abs./cm)	**E168 FTNG**	0.0	4.0	8.0	14.4	25.5	53.9	171.6
Nitration (Abs./cm)	**E168 FTNG**	0.0	4.9	5.6	7.8	14.1	28.2	36.6
Soot	**Soot**	0.1	0.4	0.6	0.5	0.7	1.1	2.0
Wear Metals (ppm)	**D5185**							
Al		<1	2	2	3	4	4	5
Sb		<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1
B		3	3	4	5	7	5	5
Ca		3024	3135	3275	3397	3413	3450	3620
Cr		<1	<1	2	3	4	4	6
Cu		<1	20	22	25	26	38	234
Fe		2	40	74	107	133	157	264
Pb		<1	13	13	14	20	52	332
Mg		9	10	10	11	11	12	13
Mn		<1	1	2	2	3	3	5
Mo		1	8	11	14	16	18	22
Ni		<1	2	2	3	4	4	6
P		1194	1113	1071	1065	1078	1090	1089
Si		5	37	44	46	47	45	51
Ag		<1	<1	<1	<1	<1	<1	<1
Na		7	5	<5	10	6	5	8
Sn		<1	7	9	9	11	11	17
Zn		1362	1348	1353	1401	1451	1488	1544
K		8	<5	<5	<5	<5	<5	<5
Sr		<1	<1	<1	<1	<1	<1	1
V		<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	1

Engine Oil Analysis Trends

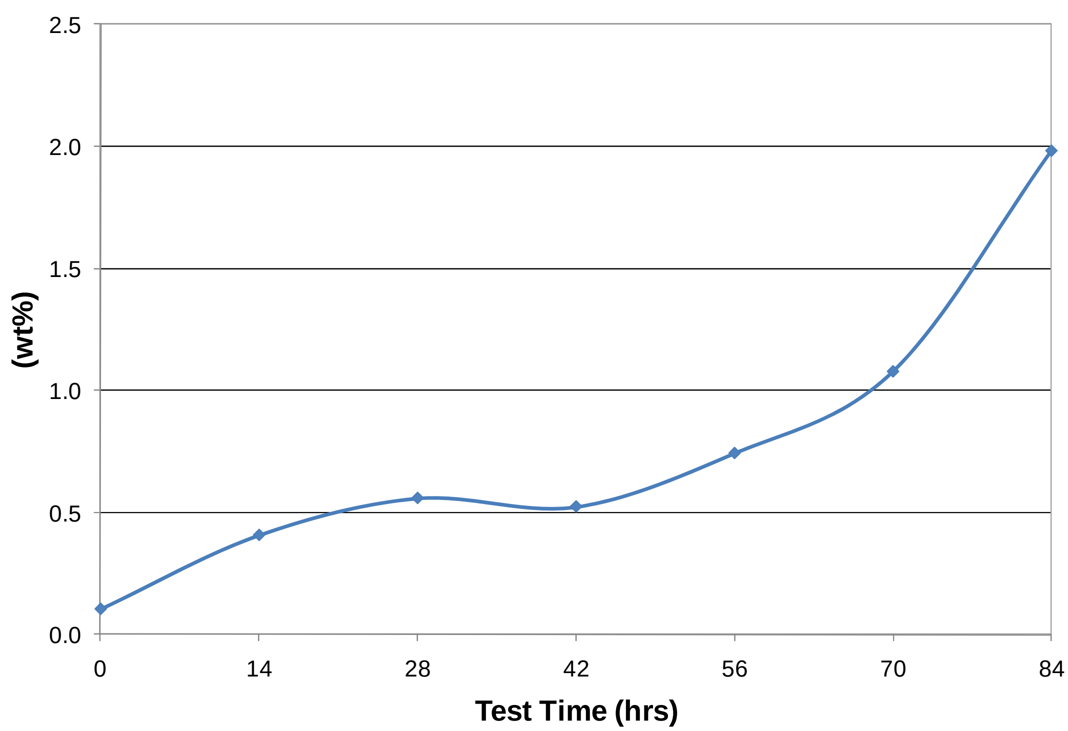


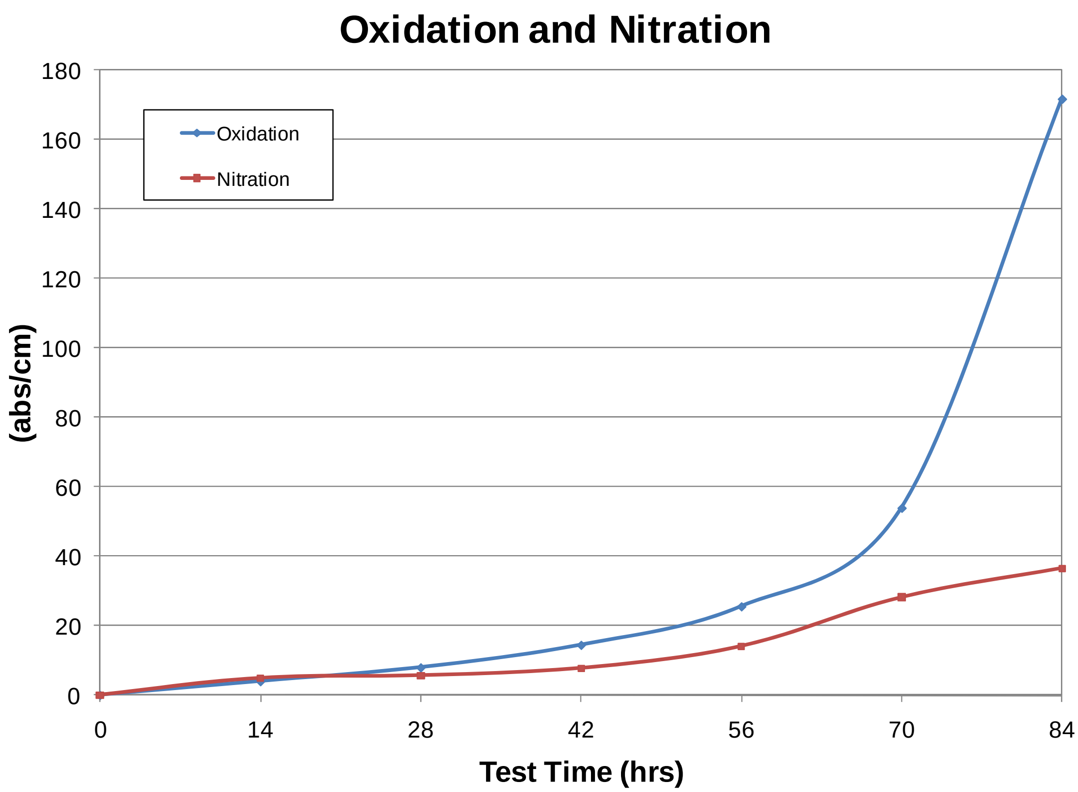


Total Acid and Base Numbers

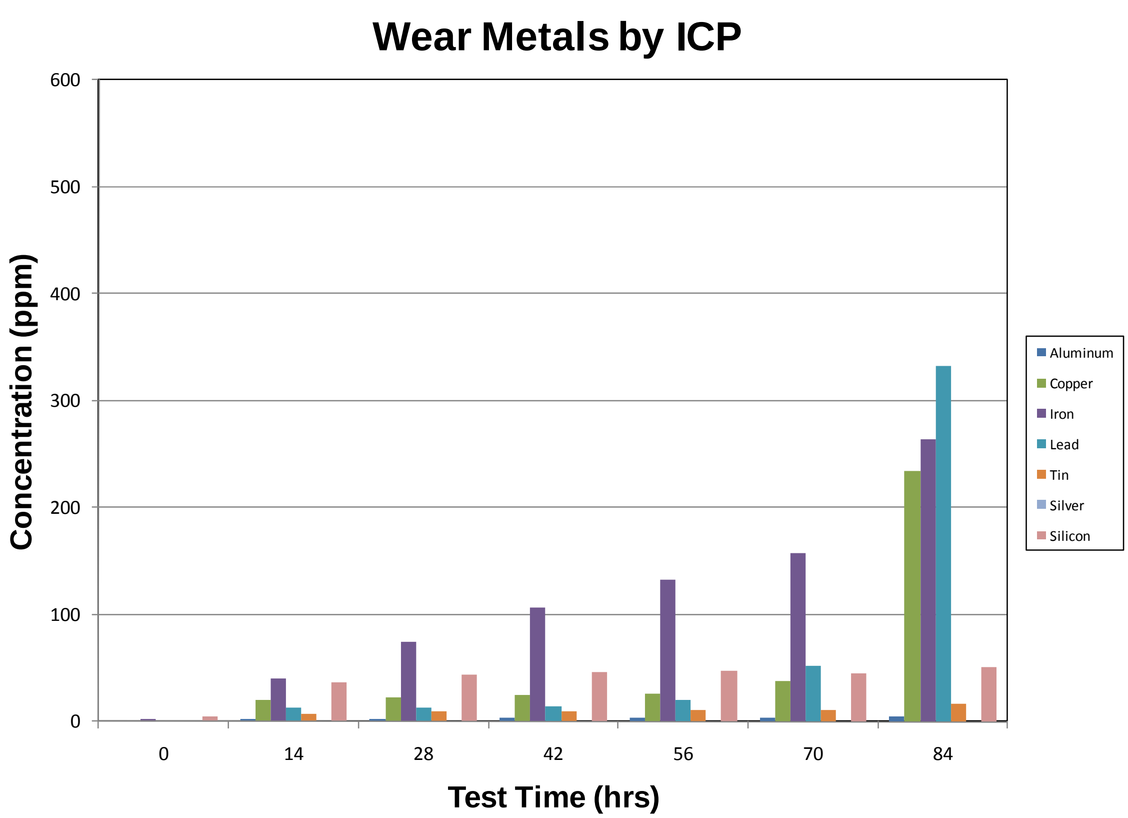


Soot





Oxidation and Nitration
180
160
140
120
100
80
60
40
20
0
(abs/cm)
Oxidation
Nitration
0
14
28
42
56
70
84
Test Time (hrs)



Wear Metals by ICP
600
500
400
300
200
100
0
Concentration (ppm)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon
0
14
28
42
56
70
84
Test Time (hrs)

Oil Consumption Data

Average oil consumption per test hour was 0.081 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14-hr	0.9	0.23	0.67	0.67
28-hr	1	0.25	0.75	1.42
42-hr	1.66	0.24	1.42	2.84
56-hr	1.08	0.25	0.83	3.67
70-hr	1.22	0.22	1	4.67
84-hr	1.7	0.26	1.44	6.11
	Initial Fill	16.23	**Total Additions**	7.56
	EOT Drain	15.56	**Total Samples**	1.45

(Initial Fill + Additions)	23.79
(EOT Drain + Samples)	17.01
Total Oil Consumption	6.78

Post Test Engine Ratings

Ratings	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.2	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.3	NO	NO	NO	NO	NO	NO	NO	NO	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	26.25	46.75	41.50	26.25	31.00	29.25	32.00	31.00	33.00
No.2 Groove	10.00	5.75	21.25	8.25	2.50	11.25	10.00	25.00	11.75
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	30.75	35.75	32.25	27.75	31.25	39.00	38.50	37.25	34.06
No.2 Land	14.50	23.25	29.00	20.25	12.25	19.75	20.25	35.25	21.81
No.3 Land	0.00	0.00	2.50	1.25	0.00	0.00	0.00	7.25	1.38
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.75	0.47
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	2.56	3.35	2.63	3.94	3.54	1.72	3.55	0.00	2.66
No.3 Groove	2.33	2.33	1.97	2.33	2.07	2.15	2.12	3.30	2.33
No.1 Land	0.04	0.01	0.05	0.06	0.02	0.02	0.03	0.01	0.03
No.2 Land	1.76	1.02	0.22	0.84	2.14	2.26	1.97	0.02	1.28
No.3 Land	2.42	3.49	4.64	3.26	2.18	4.95	4.04	3.81	3.60
Upper Skirt	0.26	0.62	0.51	0.38	0.20	0.87	0.20	0.97	0.50
Under Crown	5.50	4.77	3.63	5.10	4.36	4.82	4.37	5.73	4.79
Front Pin Bore	1.30	2.00	1.36	1.30	1.24	1.32	1.24	1.62	1.42
Rear Pin Bore	1.06	1.24	1.30	1.30	1.24	1.24	1.24	2.00	1.33
Total, Demerits	98.73	130.33	142.81	102.26	93.99	118.60	119.51	156.96	120.40
Miscellanous									
Top Groove Fill, %	15	46	40	19	19	19	20	24	25.25
Intermediate Groove Fill, %	4	2	21	11	1	4	4	20	8.38
Top Land Heavy Carbon, %	10	15	13	8	10	20	20	17	14.13
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0	0	0.00
Valve Tulip Deposits, Merits									
Exahust	9.0	9.3	9.1	9.0	9.7	9.0	9.0	9.2	9.16
Intake	8.8	8.7	8.6	7.7	7.7	7.7	8.7	8.6	8.31

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0547	4.0553	4.0548	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0000	0.0006	0.0003	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0003	0.0006	0.0005	
Piston Skirt Diameter	4.0499	4.0503	4.0501	
Piston Skirt to Cylinder Bore Clearance	0.0044	0.0054	0.0047	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.014	0.016	0.015	
Second Ring	0.032	0.039	0.035	
Oil Control Ring	0.013	0.016	0.014	
Ring To Groove Clearance				
Second Ring	0.0015	0.0015	0.0015	0.0015"-0.003"
Oil Control Ring	0.0020	0.0020	0.0020	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2213	1.2214	1.2214	1.2207"-1.2212"
Piston Pin Clearance	0.0008	0.0009	0.0009	0.0003"-0.0012"
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2213	1.2215	1.2214	1.2207"-1.2212"
Piston Pin Clearance	0.0008	0.0010	0.0009	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0025	0.0030	0.0029	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0030	0.0022	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.006	0.004-0.010"
Rod Side Clearance	0.012	0.014	0.013	0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0549	4.0547		0.0002
	Middle	4.0548	4.0543	4.0547	0.0005
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0004	0.0004		
2	Top	4.0551	4.0547		0.0004
	Middle	4.0549	4.0543	4.0548	0.0006
	Bottom	4.0546	4.0544		0.0002
	Taper	0.0005	0.0004		
3	Top	4.0551	4.0546		0.0005
	Middle	4.0548	4.0543	4.0547	0.0005
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0006	0.0003		
4	Top	4.0550	4.0547		0.0003
	Middle	4.0548	4.0543	4.0547	0.0005
	Bottom	4.0545	4.0545		0.0000
	Taper	0.0005	0.0004		
5	Top	4.0551	4.0546		0.0005
	Middle	4.0548	4.0543	4.0547	0.0005
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0006	0.0003		
6	Top	4.0551	4.0546		0.0005
	Middle	4.0548	4.0543	4.0547	0.0005
	Bottom	4.0545	4.0545		0.0000
	Taper	0.0006	0.0003		
7	Top	4.0556	4.0556		0.0000
	Middle	4.0555	4.0554	4.0553	0.0001
	Bottom	4.0551	4.0551		0.0000
	Taper	0.0005	0.0005		
8	Top	4.0557	4.0553		0.0004
	Middle	4.0555	4.0549	4.0553	0.0006
	Bottom	4.0551	4.0551		0.0000
	Taper	0.0006	0.0004		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0553	4.0549		0.0004
	Middle	4.0550	4.0542	4.0549	0.0008
	Bottom	4.0547	4.0545		0.0002
	Taper	0.0006	0.0007		
2	Top	4.0546	4.0554		0.0008
	Middle	4.0543	4.0550	4.0544	0.0007
	Bottom	4.0545	4.0547		0.0002
	Taper	0.0003	0.0007		
3	Top	4.0547	4.0553		0.0006
	Middle	4.0543	4.0550	4.0544	0.0007
	Bottom	4.0545	4.0546		0.0001
	Taper	0.0004	0.0007		
4	Top	4.0547	4.0551		0.0004
	Middle	4.0542	4.0549	4.0542	0.0007
	Bottom	4.0542	4.0546		0.0004
	Taper	0.0005	0.0005		
5	Top	4.0546	4.0553		0.0007
	Middle	4.0542	4.0550	4.0544	0.0008
	Bottom	4.0546	4.0546		0.0000
	Taper	0.0004	0.0007		
6	Top	4.0544	4.0554		0.0010
	Middle	4.0541	4.0550	4.0543	0.0009
	Bottom	4.0544	4.0545		0.0001
	Taper	0.0003	0.0009		
7	Top	4.0554	4.0558		0.0004
	Middle	4.0550	4.0556	4.0550	0.0006
	Bottom	4.0549	4.0552		0.0003
	Taper	0.0005	0.0006		
8	Top	4.0554	4.0559		0.0005
	Middle	4.0548	4.0556	4.0549	0.0008
	Bottom	4.0549	4.0553		0.0004
	Taper	0.0006	0.0006		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0004	0.0002	
	Middle	0.0002	0.0001	0.0002
	Bottom	0.0002	0.0001	
2	Top	0.0005	0.0007	
	Middle	0.0006	0.0007	0.0004
	Bottom	0.0001	0.0003	
3	Top	0.0004	0.0007	
	Middle	0.0005	0.0007	0.0003
	Bottom	0.0000	0.0002	
4	Top	0.0003	0.0004	
	Middle	0.0006	0.0006	0.0005
	Bottom	0.0003	0.0001	
5	Top	0.0005	0.0007	
	Middle	0.0006	0.0007	0.0004
	Bottom	0.0001	0.0002	
6	Top	0.0007	0.0008	
	Middle	0.0007	0.0007	0.0004
	Bottom	0.0001	0.0000	
7	Top	0.0002	0.0002	
	Middle	0.0005	0.0002	0.0004
	Bottom	0.0002	0.0001	
8	Top	0.0003	0.0006	
	Middle	0.0007	0.0007	0.0005
	Bottom	0.0002	0.0002	
Avgerage All Cylinders	Top	0.0004	0.0005	
	Middle	0.0006	0.0006	
	Bottom	0.0002	0.0001	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter			Valve Guide Diameter		
	Intake			Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3431	0.3433	0.0002	0.3733	0.3739	0.0006
2	0.3431	0.3432	0.0001	0.3733	0.3752	0.0019
3	0.3431	0.3431	0.0000	0.3733	0.3738	0.0005
4	0.3431	0.3431	0.0000	0.3733	0.3752	0.0019
5	0.3431	0.3434	0.0003	0.3733	0.3737	0.0004
6	0.3431	0.3432	0.0001	0.3733	0.3742	0.0009
7	0.3431	0.3431	0.0000	0.3733	0.3739	0.0006
8	0.3431	0.3432	0.0001	0.3733	0.3739	0.0006

Maximum	0.0003
Average	0.0001

Maximum	0.0019
Average	0.0009

Valve Stem Measurement Changes, inches

	Valve Stem Diameter			Valve Stem Diameter		
	Intake			Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3412	0.3410	0.0002	0.3714	0.3710	0.0004
2	0.3412	0.3411	0.0001	0.3714	0.3706	0.0008
3	0.3412	0.3411	0.0001	0.3714	0.3709	0.0005
4	0.3412	0.3410	0.0002	0.3714	0.3707	0.0007
5	0.3411	0.3410	0.0001	0.3714	0.3708	0.0006
6	0.3412	0.3412	0.0000	0.3714	0.3709	0.0005
7	0.3412	0.3411	0.0001	0.3713	0.3708	0.0005
8	0.3412	0.3411	0.0001	0.3714	0.3709	0.0005

Maximum	0.0002
Average	0.0001

Maximum	0.0008
Average	0.0006

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance			Stem Guide Clearance		
	Intake			Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0019	0.0023	0.0004	0.0019	0.0029	0.0010
2	0.0019	0.0021	0.0002	0.0019	0.0046	0.0027
3	0.0019	0.0020	0.0001	0.0019	0.0029	0.0010
4	0.0019	0.0021	0.0002	0.0019	0.0045	0.0026
5	0.0020	0.0024	0.0004	0.0019	0.0029	0.0010
6	0.0019	0.0020	0.0001	0.0019	0.0033	0.0014
7	0.0019	0.0020	0.0001	0.0020	0.0031	0.0011
8	0.0019	0.0021	0.0002	0.0019	0.0030	0.0011

Maximum	0.0004
Average	0.0002

Maximum	0.0027
Average	0.0015

Valve Recession Measurement Changes, inches

	Valve Recession			Valve Recession		
	Intake			Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.026	0.049	0.023	0.022	0.024	0.002
2	0.024	0.040	0.016	0.028	0.031	0.003
3	0.023	0.044	0.021	0.025	0.029	0.004
4	0.024	0.046	0.022	0.027	0.030	0.003
5	0.023	0.050	0.027	0.025	0.028	0.003
6	0.023	0.046	0.023	0.024	0.027	0.003
7	0.024	0.048	0.024	0.025	0.027	0.002
8	0.024	0.056	0.032	0.025	0.027	0.002

Maximum	0.032
Average	0.024

Maximum	0.004
Average	0.003

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	1.79
2	1.33
3	1.41
4	1.19
5	1.53
6	1.48
7	1.75
8	1.53
9	1.38
10	1.62
11	1.25
12	1.31
13	1.27
14	1.40
15	1.21
16	1.61

Maximum	1.79
Average	1.44

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0547	4.0499	0.0048
	2	4.0548	4.0502	0.0046
	3	4.0547	4.0502	0.0045
	4	4.0547	4.0501	0.0046
	5	4.0547	4.0500	0.0047
	6	4.0547	4.0503	0.0044
	7	4.0553	4.0501	0.0052
	8	4.0553	4.0499	0.0054
Post - Test	1	4.0549	4.0494	0.0054
	2	4.0544	4.0495	0.0049
	3	4.0544	4.0499	0.0045
	4	4.0542	4.0495	0.0047
	5	4.0544	4.0493	0.0051
	6	4.0543	4.0494	0.0048
	7	4.0550	4.0496	0.0053
	8	4.0549	4.0493	0.0056

Top and Second Ring Radial Wear, inches

Top Ring						Second Ring				
Cylinder	Position	Before	After	Delta		Cylinder	Position	Before	After	Delta
1	1	0.17935	0.17895	0.00040		1	1	0.16100	0.16020	0.00080
	2	0.17870	0.17830	0.00040			2	0.16140	0.16075	0.00065
	3	0.17920	0.17885	0.00035			3	0.16190	0.16125	0.00065
	4	0.18080	0.18050	0.00030			4	0.16135	0.16080	0.00055
	5	0.17990	0.17955	0.00035			5	0.16095	0.16025	0.00070
2	1	0.17860	0.17830	0.00030		2	1	0.16160	0.16100	0.00060
	2	0.17885	0.17845	0.00040			2	0.16235	0.16170	0.00065
	3	0.18050	0.18010	0.00040			3	0.16205	0.16145	0.00060
	4	0.18010	0.17990	0.00020			4	0.16215	0.16170	0.00045
	5	0.17925	0.17895	0.00030			5	0.16170	0.16130	0.00040
3	1	0.17850	0.17825	0.00025		3	1	0.16180	0.16120	0.00060
	2	0.17865	0.17815	0.00050			2	0.16245	0.16170	0.00075
	3	0.17885	0.17860	0.00025			3	0.16205	0.16145	0.00060
	4	0.17870	0.17845	0.00025			4	0.16210	0.16135	0.00075
	5	0.17800	0.17775	0.00025			5	0.16150	0.16120	0.00030
4	1	0.17925	0.17900	0.00025		4	1	0.16250	0.16200	0.00050
	2	0.17880	0.17850	0.00030			2	0.16315	0.16270	0.00045
	3	0.17850	0.17830	0.00020			3	0.16305	0.16250	0.00055
	4	0.17970	0.17940	0.00030			4	0.16315	0.16265	0.00050
	5	0.17955	0.17910	0.00045			5	0.16250	0.16185	0.00065
5	1	0.17900	0.17865	0.00035		5	1	0.16050	0.15985	0.00065
	2	0.17895	0.17860	0.00035			2	0.16110	0.16020	0.00090
	3	0.18060	0.18030	0.00030			3	0.16205	0.16155	0.00050
	4	0.17985	0.17945	0.00040			4	0.16240	0.16160	0.00080
	5	0.17895	0.17875	0.00020			5	0.16120	0.16015	0.00105
6	1	0.17935	0.17890	0.00045		6	1	0.16215	0.16155	0.00060
	2	0.17975	0.17940	0.00035			2	0.16275	0.16195	0.00080
	3	0.17930	0.17915	0.00015			3	0.16225	0.16145	0.00080
	4	0.17935	0.17900	0.00035			4	0.16275	0.16185	0.00090
	5	0.17915	0.17890	0.00025			5	0.16175	0.16095	0.00080
7	1	0.17925	0.17895	0.00030		7	1	0.16230	0.16160	0.00070
	2	0.17950	0.17930	0.00020			2	0.16250	0.16200	0.00050
	3	0.17830	0.17775	0.00055			3	0.16240	0.16175	0.00065
	4	0.17780	0.17740	0.00040			4	0.16280	0.16230	0.00050
	5	0.17900	0.17870	0.00030			5	0.16260	0.16160	0.00100
8	1	0.17885	0.17835	0.00050		8	1	0.16190	0.16075	0.00115
	2	0.17850	0.17780	0.00070			2	0.16230	0.16135	0.00095
	3	0.17955	0.17905	0.00050			3	0.16255	0.16150	0.00105
	4	0.17915	0.17865	0.00050			4	0.16190	0.16070	0.00120
	5	0.17895	0.17850	0.00045			5	0.16105	0.15995	0.00110

Maximum	0.00070		Maximum	0.00120
Average	0.00035		Average	0.00071

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.014	0.014	0.000
	2	0.032	0.040	0.008
	3	0.014	0.015	0.001
2	1	0.015	0.017	0.002
	2	0.036	0.037	0.001
	3	0.014	0.015	0.001
3	1	0.014	0.016	0.002
	2	0.032	0.035	0.003
	3	0.013	0.014	0.001
4	1	0.015	0.016	0.001
	2	0.036	0.035	-0.001
	3	0.013	0.014	0.001
5	1	0.014	0.014	0.000
	2	0.033	0.040	0.007
	3	0.013	0.014	0.001
6	1	0.015	0.016	0.001
	2	0.036	0.036	0.000
	3	0.014	0.014	0.000
7	1	0.016	0.016	0.000
	2	0.039	0.040	0.001
	3	0.016	0.016	0.000
8	1	0.016	0.017	0.001
	2	0.039	0.041	0.002
	3	0.015	0.018	0.003

Ring No. 1 max increase	0.002
Ring No. 2 max increase	0.008
Ring No. 3 max increase	0.003

Ring No. 1 avg increase	0.001
Ring No. 2 avg increase	0.003
Ring No. 3 avg increase	0.001

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.5943	22.5536	0.0407
	2	16.9117	16.8904	0.0213
	3	15.1293	15.1134	0.0159
2	1	22.7386	22.6928	0.0458
	2	17.0818	17.0635	0.0183
	3	15.2356	15.2231	0.0125
3	1	22.7737	22.7167	0.0570
	2	16.9296	16.9088	0.0208
	3	15.1214	15.1062	0.0152
4	1	22.6437	22.6003	0.0434
	2	17.1300	17.1133	0.0167
	3	15.2374	15.2230	0.0144
5	1	22.6130	22.5682	0.0448
	2	16.8961	16.8717	0.0244
	3	15.1303	15.1160	0.0143
6	1	22.6785	22.6277	0.0508
	2	17.0688	17.0471	0.0217
	3	15.3175	15.3031	0.0144
7	1	22.8561	22.8084	0.0477
	2	17.0653	17.0460	0.0193
	3	15.1343	15.1231	0.0112
8	1	22.6119	22.4997	0.1122
	2	16.9117	16.8697	0.0420
	3	14.7395	14.7124	0.0271

Ring No. 1 max decrease	0.1122
Ring No. 2 max decrease	0.0420
Ring No. 3 max decrease	0.0271

Ring No. 1 avg decrease	0.0553
Ring No. 2 avg decrease	0.0231
Ring No. 3 avg decrease	0.0156

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.7235	27.6978	0.0257
	Bottom	27.8374	27.7429	0.0945
2	Top	27.8280	27.7967	0.0313
	Bottom	27.7451	27.7261	0.0190
3	Top	27.8171	27.8092	0.0079
	Bottom	27.7661	27.7545	0.0116
4	Top	27.7819	27.7737	0.0082
	Bottom	27.7007	27.6870	0.0137
5	Top	27.9343	27.9076	0.0267
	Bottom	27.9268	27.8452	0.0816
6	Top	27.9743	27.9526	0.0217
	Bottom	27.9152	27.8905	0.0247
7	Top	27.7633	27.7472	0.0161
	Bottom	27.8392	27.7991	0.0401
8	Top	27.7081	27.6998	0.0083
	Bottom	27.8820	27.8291	0.0529

Maximum	0.0945
Average	0.0303

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.5831	48.5606	0.0225
	Bottom	52.4940	52.4744	0.0196
2	Top	48.1454	48.1318	0.0136
	Bottom	52.6911	52.6533	0.0378
3	Top	94.1237	93.2058	0.9179
	Bottom	99.8360	97.6085	2.2275
4	Top	47.9387	47.9277	0.0110
	Bottom	51.7949	51.7652	0.0297
5	Top	69.5484	69.5020	0.0464
	Bottom	73.7315	73.6893	0.0422

Maximum	2.2275
Average	0.3368

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 15241802**
Test condition : SCPL Candidate Testing	

PUMP RPM	Description	Spec.	Before	After	Change
1000	Transfer pump psi.	60-62 psi	62	61	1
	Return Fuel	225-375 cc	240	345	105
350	Low Idle	12-16 cc	16	18	2
	Housing psi.	8-12 psi	10	9	1
	Advance	3.5 deg. min	6.03	5.92	0.11
	Cold Advance Solenoid	0-1 psi.	0	0	0
750	Shut-Off	4 cc max.	0.5	0.5	0
900	Fuel Delivery	66.5 - 69.5cc	67	67	0
1600	WOT Fuel delivery	59.5 min.	64	64	0
	WOT Advance	2.5 - 3.5 deg.	3.21	3.02	0.19
	Face Cam Fuel delivery	21.5 - 23.5	22	22	0
	Face Cam Advance	5.25 - 7.25 deg.	6.75	6.73	0.02
	Low Idle	11 - 12 deg.	11.25	11.19	0.06
1825	Fuel Delivery	33 cc min.	37.5	44	6.5
1950	High Idle	15 cc max.	2	4	2
	Transfer pump psi.	125 psi max.	102	100	2
200	WOT Fuel Delivery	58 cc min.	62	62	0
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	50	51	1
	Transfer pump psi.	16 psi min.	25	25	0
	Housing psi.	0 -12 psi	6	6	0
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5	-0.5	0
	Fluid Temp. Deg. C				
	Date				

*Pump calibration data to be used for reference only

Photographs

Oil Code:	LO246362	EOT Date:	08/23/10
Test No.:	LO246362-65T1-W-210	Test Length:	84

Piston Skirt Thrust - Best Cyl 5

Piston Skirt Anti-thrust - Best Cyl 5

Oil Code:	LO246362	EOT Date:	08/23/10
Test No.:	LO246362-65T1-W-210	Test Length:	84

Piston Skirt Thrust - Worst Cyl 8

Piston Skirt Anti-thrust - Worst Cyl 8

GEP 6.5 - Wheeled Vehicle Cycle

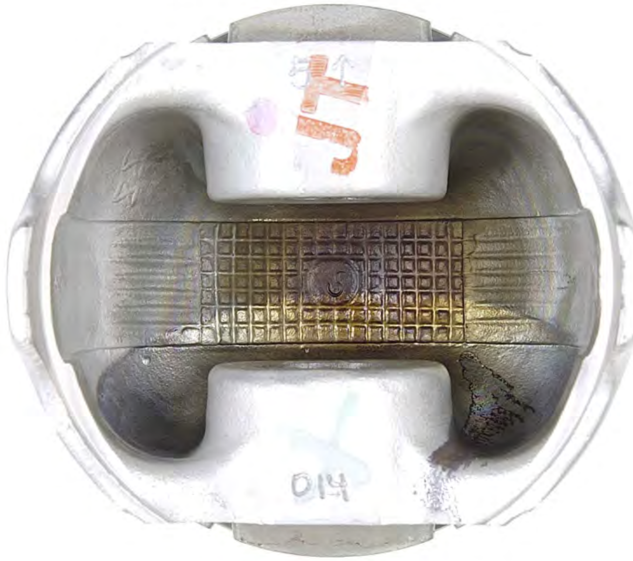
Oil Code:	LO246362	**EOT Date:**	08/23/10
Test No.:	LO246362-65T1-W-210	**Test Length:**	84

Piston Rings - Best Cyl 4

Piston Rings - Worst Cyl 8

Oil Code:	LO246362	EOT Date:	08/23/10
Test No.:	LO246362-65T1-W-210	Test Length:	84

Piston Undercrown - Best Cyl 5



Piston Undercrown - Worst Cyl 8

Oil Code:	LO246362	EOT Date:	08/23/10
Test No.:	LO246362-65T1-W-210	Test Length:	84

Engine Block Cylinder Bore - Best Cyl 5

Engine Block Cylinder Bore - Worst Cyl 2

Oil Code:	LO246362	EOT Date:	08/23/10
Test No.:	LO246362-65T1-W-210	Test Length:	84

Exhaust and Intake Valve - Best Cyl 2

Oil Code:	LO246362	**EOT Date:**	08/23/10
Test No.:	LO246362-65T1-W-210	**Test Length:**	84

Exhaust and Intake Valve - Worst Cyl 7

Oil Code:	LO246362	EOT Date:	08/23/10
Test No.:	LO246362-65T1-W-210	Test Length:	84

Rod Bearings

Oil Code:	LO246362	EOT Date:	08/23/10
Test No.:	LO246362-65T1-W-210	Test Length:	84

Main Bearings

APPENDIX B2. – EVALUATION OF MIL-PRF-2104H IN THE 6.5L(T) HIGH TEMPERATURE OIL ENDURANCE TEST

EVALUATION OF SCPL CANDIDATE LO-257264 MIL-PRF-2104H Baseline

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-257264
Test Fuel: Jet-A w/DCI-4A
Test Number: LO257264-65T1-W-210
Start of Test Date: January 10, 2011
End of Test Date: January 24, 2011
Test Duration: 154 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-257264 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

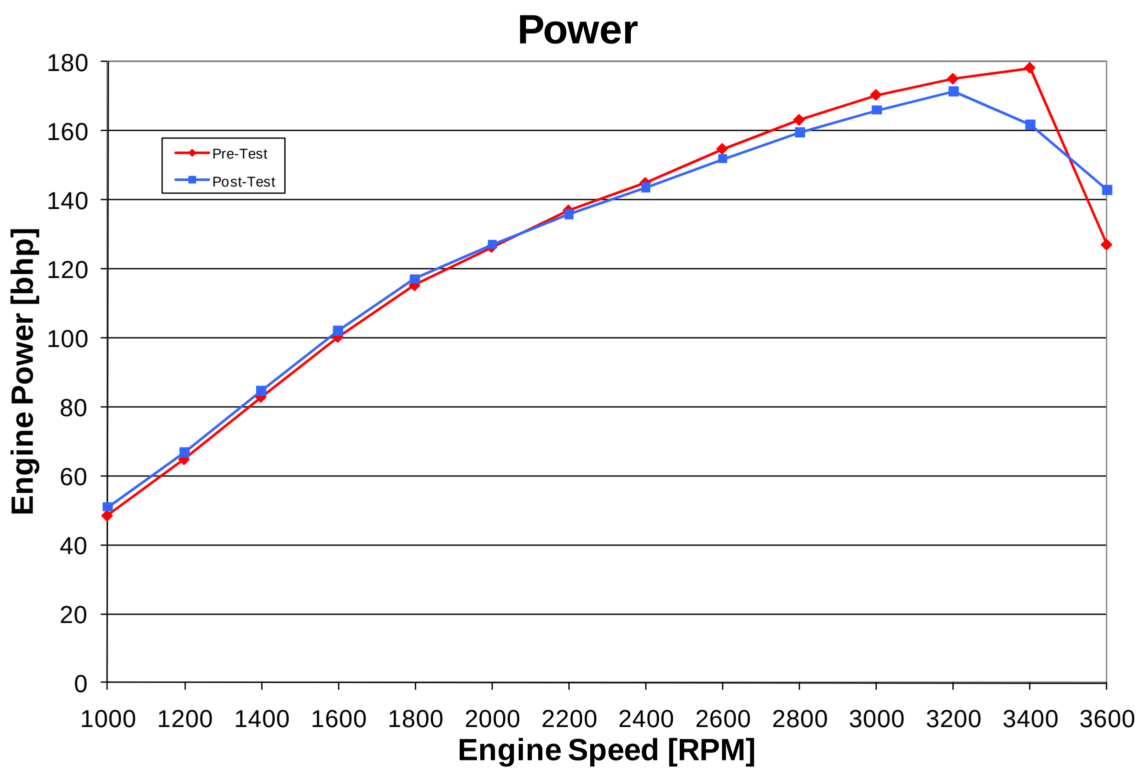
Engine Operating Conditions Summary

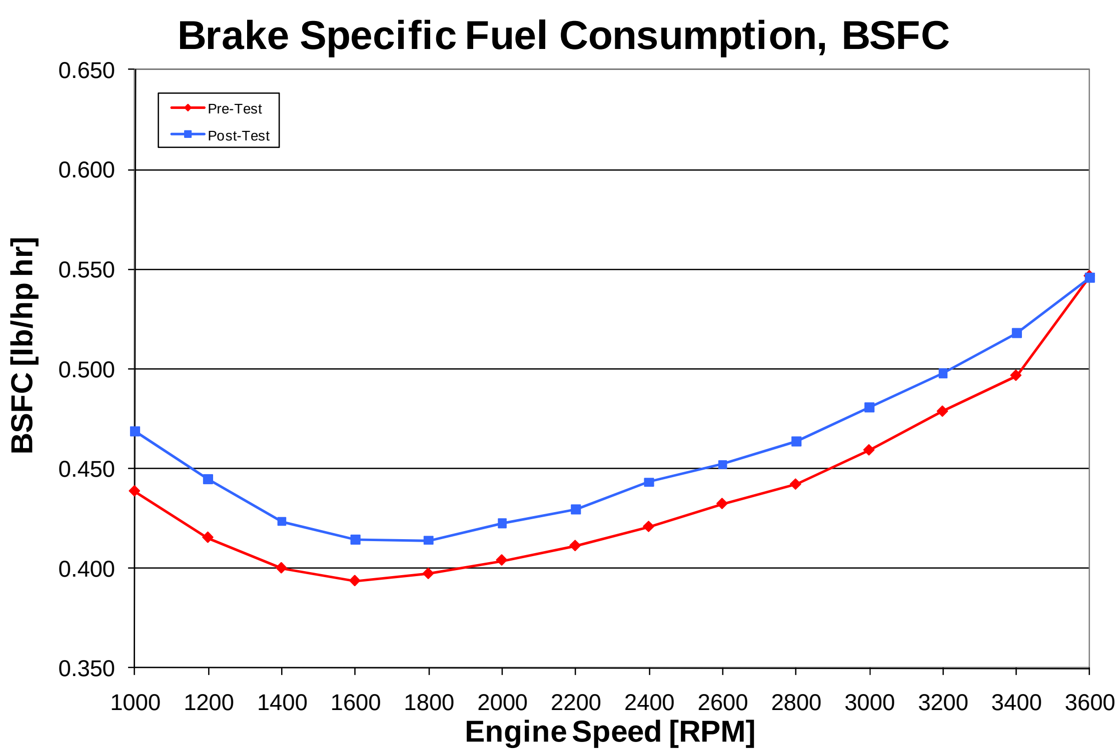
Below is a summary of the engine operating conditions over the test duration. Testing was stopped at 154hrs due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.03	0.71	900.63	6.28
Torque*	ft*lb	255.65	1.59	29.41	2.15
Fuel Flow	lb/hr	78.63	1.18	6.07	0.36
Power*	bhp	165.51	1.01	5.04	0.38
BSFC*	lb/bhp*hr	0.475	0.008	1.208	0.079
Temperatures:					
Coolant In	°F	191.39	1.05	92.49	0.66
Coolant Out	°F	204.99	0.96	100.00	0.53
Oil Sump	°F	260.15	0.71	125.93	1.96
Fuel In	°F	95.00	0.36	94.98	0.33
Intake Air	°F	62.95	10.05	61.14	9.34
Cylinder 1 Exhaust	°F	976.82	27.28	177.26	7.78
Cylinder 2 Exhaust	°F	1038.54	32.21	173.40	8.81
Cylinder 3 Exhaust	°F	1060.20	33.06	170.16	8.50
Cylinder 4 Exhaust	°F	1030.32	26.52	184.44	6.60
Cylinder 5 Exhaust	°F	1097.57	33.08	178.08	7.82
Cylinder 6 Exhaust	°F	1068.33	26.94	186.35	6.86
Cylinder 7 Exhaust	°F	1017.64	26.96	171.46	7.45
Cylinder 8 Exhaust	°F	1092.78	34.95	183.93	7.84
Pressures:					
Oil Galley	psi	43.63	1.49	51.80	2.29
Ambient Pressure	psiA	14.40	0.14	14.39	0.13
Boost Pressure	psi	4.85	0.09	-0.21	0.05

* Non-corrected Values

Engine Performance Curves

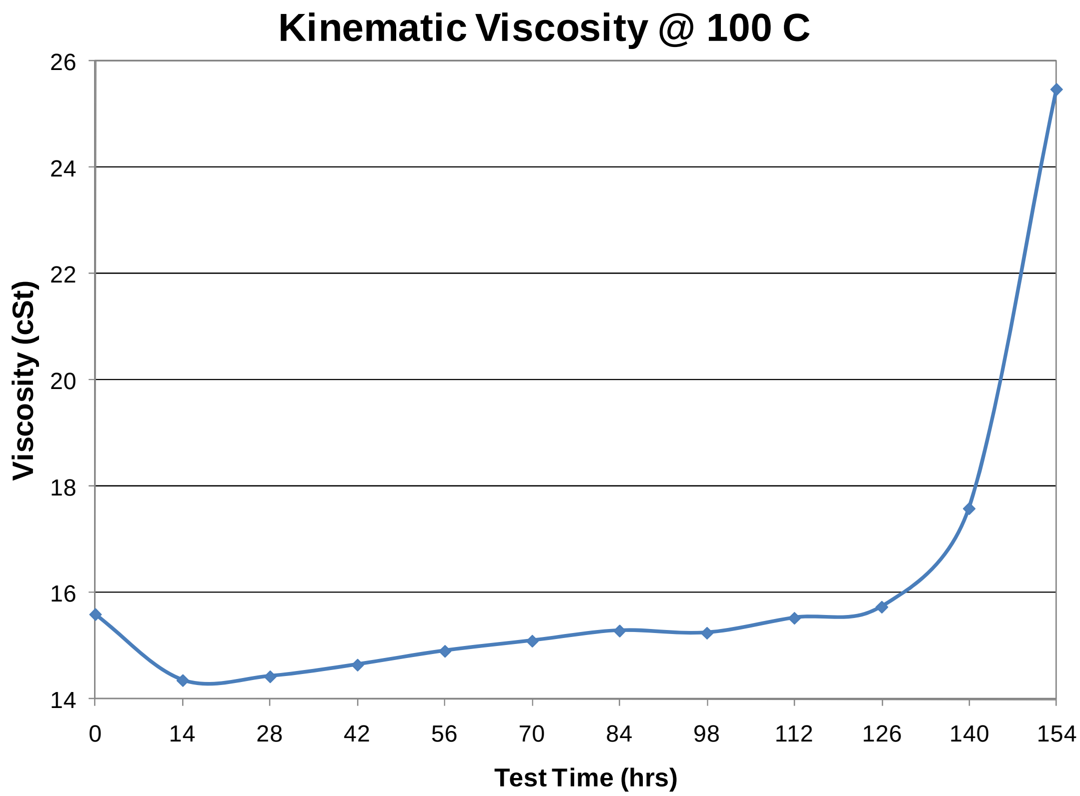


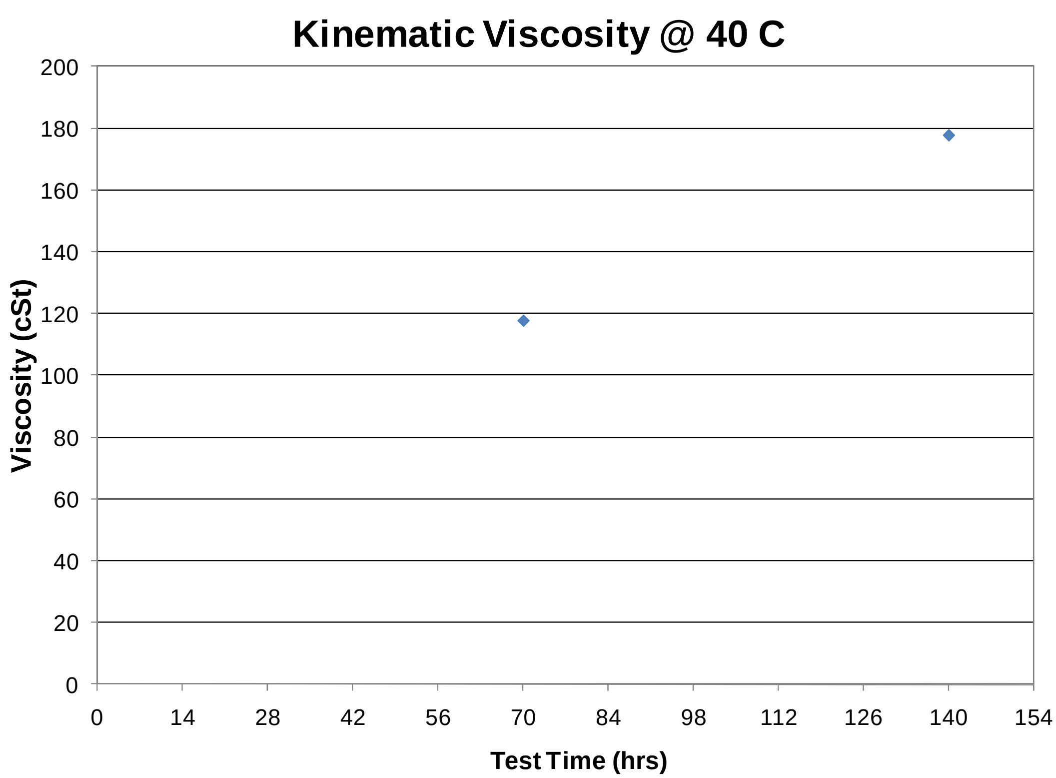


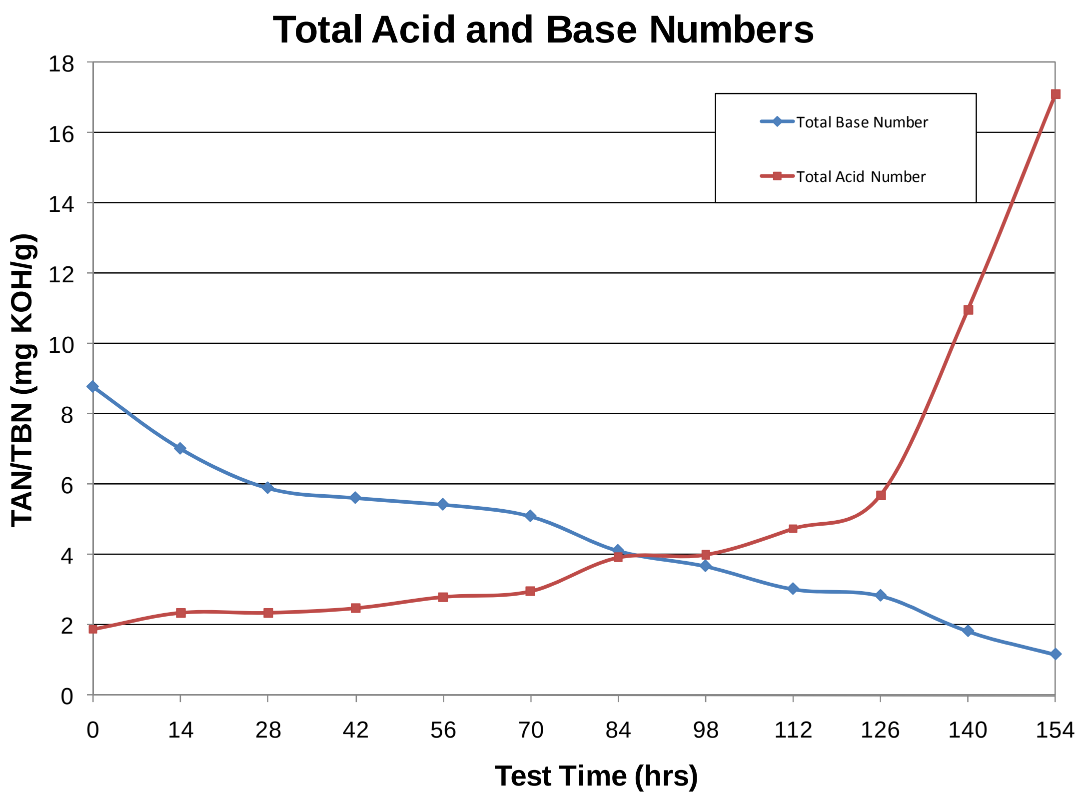
Engine Oil Analysis

Property	ASTM Test	Test Hours											
		0	14	28	42	56	70	84	98	112	126	140	154
Density	D4052	0.872	0.875	0.876	0.875	0.879	0.880	0.882	0.884	0.887	0.892	IC	0.928
Viscosity @ 100°C (cSt)	D445	15.6	14.4	14.4	14.7	14.9	15.1	15.3	15.3	15.5	15.7	17.6	25.5
Viscosity @ 40°C (cSt)	D445						117.6					177.6	
Viscosity Index (dyne/cm)	D2270						133.0					108.0	
Total Base Number (mg KOH/g)	D4739	8.8	7.0	5.9	5.6	5.4	5.1	4.1	3.7	3.0	2.8	1.8	1.2
Total Acid Number (mg KOH/g)	D664	1.9	2.4	2.4	2.5	2.8	3.0	3.9	4.0	4.7	5.7	11.0	17.1
Oxidation (Abs./cm)	E168 FTNG	0.0	3.6	6.3	8.8	11.2	14.3	18.5	30.4	39.2	51.4	116.0	218.0
Nitration (Abs./cm)	E168 FTNG	0.0	3.3	3.0	3.0	3.4	4.3	7.2	15.0	21.1	26.0	33.2	33.8
Soot	Soot	0.1	0.2	0.4	0.4	0.6	0.5	0.7	1.0	1.0	1.2	1.7	2.9
Wear Metals (ppm)	D5185												
Al		<1	2	2	2	2	2	2	3	4	4	4	5
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		2	3	3	3	4	3	4	3	3	4	6	4
Ca		2380	2446	2496	2576	2627	2666	2696	2790	2863	2874	2951	3056
Cr		<1	<1	2	2	2	3	3	4	5	5	5	6
Cu		<1	18	19	20	20	21	22	22	24	27	88	345
Fe		1	43	73	91	106	122	150	163	213	246	337	468
Pb		<1	17	18	19	19	20	22	30	47	86	280	693
Mg		280	294	312	323	319	322	336	332	353	345	374	380
Mn		<1	1	2	2	2	2	3	3	4	4	5	6
Mo		1	6	9	10	12	13	14	16	16	17	18	21
Ni		<1	1	2	2	3	3	3	4	4	4	5	6
P		1198	1177	1165	1162	1147	1159	1182	1201	1229	1256	1289	1302
Si		4	32	38	40	39	38	38	36	37	36	37	38
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sn		<1	7	9	10	11	12	12	13	14	14	16	24
Zn		1389	1406	1423	1475	1464	1492	1516	1595	1631	1636	1708	1914
K		5	<5	<5	<5	<5	<5	5	<5	5	<5	<5	<5
Sr		<1	1	<1	<1	1	<1	<1	1	<1	1	<1	<1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

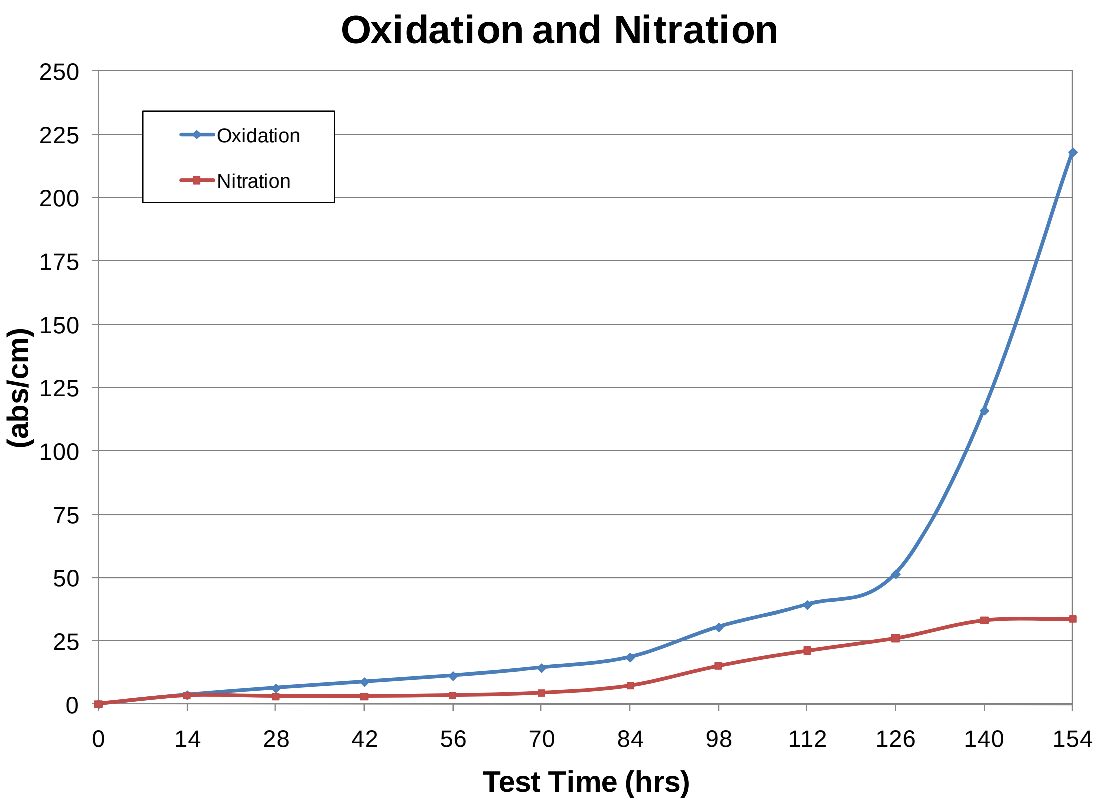
Engine Oil Analysis Trends



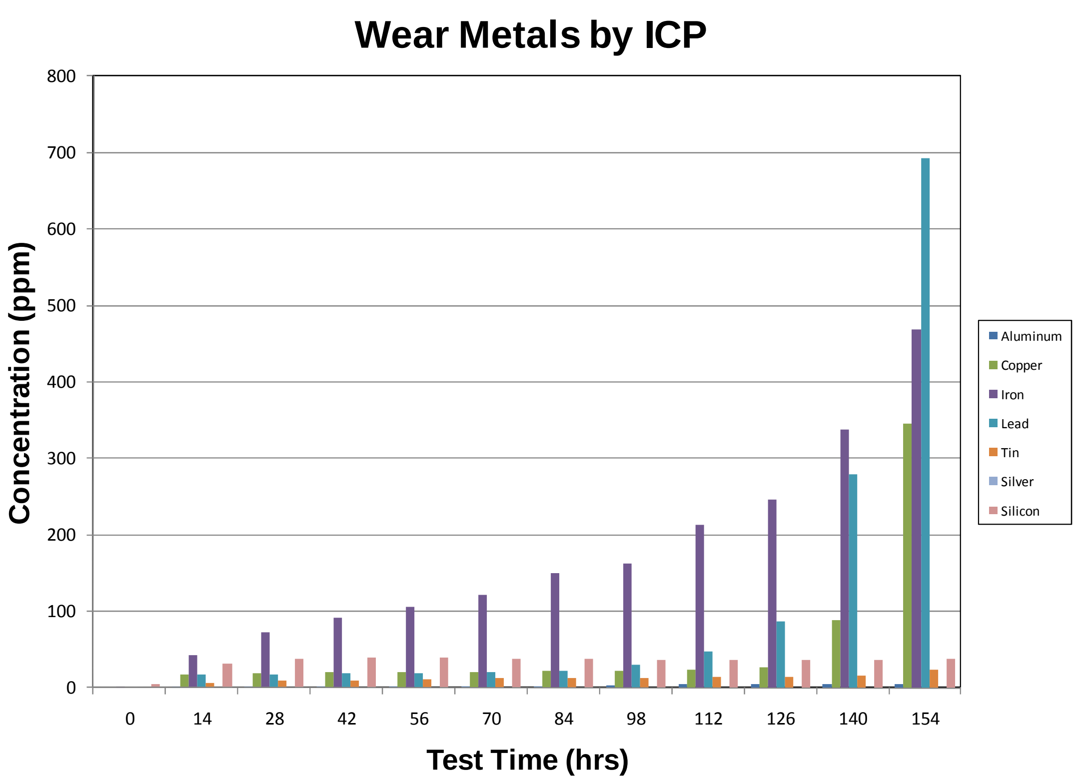



Total Acid and Base Numbers
TAN/TBN (mg KOH/g)
Test Time (hrs)
Total Base Number
Total Acid Number
0
2
4
6
8
10
12
14
16
18
0
14
28
42
56
70
84
98
112
126
140
154


Soot
(wt%)
Test Time (hrs)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
0
14
28
42
56
70
84
98
112
126
140
154



Oxidation and Nitration
Oxidation
Nitration
(abs/cm)
250
225
200
175
150
125
100
75
50
25
0
0
14
28
42
56
70
84
98
112
126
140
154
Test Time (hrs)



Wear Metals by ICP
Concentration (ppm)
800
700
600
500
400
300
200
100
0
0
14
28
42
56
70
84
98
112
126
140
154
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

Oil Consumption Data

Average oil consumption per test hour was 0.069 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14-hr	0.9	0.27	0.63	0.63
28-hr	1.61	0.24	1.37	2
42-hr	1.32	0.24	1.08	3.08
56-hr	1.68	0.23	1.45	4.53
70-hr	1.25	0.24	1.01	5.54
84-hr	1.56	0.23	1.33	6.87
98-hr	1.15	0.25	0.9	7.77
112-hr	1.58	0.25	1.33	9.1
126-hr	1.45	0.25	1.2	10.3
140-hr	1.47	0.26	1.21	11.51
154-hr	1.93	0.27	1.66	13.17
	Initial Fill	14.08	**Total Additions**	15.9
	EOT Drain	16.55	**Total Samples**	2.73

(Initial Fill + Additions)	29.98
(EOT Drain + Samples)	19.28
Total Oil Consumption	10.7

Post Test Engine Ratings

Ratings	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.2	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.3	NO	NO	NO	NO	NO	NO	NO	NO	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	44.00	90.50	41.00	52.50	32.25	69.75	46.50	57.00	54.19
No.2 Groove	14.00	38.75	11.75	4.50	7.25	1.00	13.75	17.50	13.56
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	34.50	31.25	38.75	42.25	39.50	55.00	41.50	55.00	42.22
No.2 Land	17.25	13.75	34.25	6.50	17.00	13.25	19.50	25.00	18.31
No.3 Land	2.00	1.25	4.00	0.00	0.00	0.50	2.00	3.75	1.69
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	6.25	0.00	6.25	0.00	0.00	6.25	0.00	12.50	3.91
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.63	0.36	0.00	0.00	0.00	0.00	0.12
No.2 Groove	4.61	3.94	1.82	3.96	3.83	4.94	1.68	2.26	3.38
No.3 Groove	4.35	0.29	3.18	2.64	3.35	2.99	2.40	3.78	2.87
No.1 Land	0.02	0.02	0.15	0.26	0.04	0.00	0.00	0.00	0.06
No.2 Land	1.42	2.22	0.23	3.30	1.14	3.77	1.55	0.74	1.80
No.3 Land	2.83	3.99	3.75	2.82	4.50	3.40	2.81	4.19	3.54
Upper Skirt	0.74	0.22	1.00	0.80	0.60	0.90	0.60	1.37	0.78
Under Crown	5.05	0.83	4.07	4.32	6.12	2.62	6.62	2.76	4.05
Front Pin Bore	1.30	1.70	1.30	1.30	1.70	1.30	1.30	1.30	1.40
Rear Pin Bore	1.30	1.70	1.54	1.54	1.70	1.30	1.06	1.70	1.48
Total, Demerits	139.62	190.41	153.67	127.05	118.98	166.97	141.27	188.85	153.35
Miscellanous									
Top Groove Fill, %	29	92	25	45	17	64	40	54	45.75
Intermediate Groove Fill, %	10	32	7	2	5	0	9	22	10.88
Top Land Heavy Carbon, %	14	10	20	25	20	40	22	40	23.88
Top Lan Flaked Carbon, %	0	1	0	0	0	0	0	0	0.13
Valve Tulip Deposits, Merits									
Exahust	9.7	9.1	9.6	9.1	9.7	9.2	9.1	9.0	9.31
Intake	8.3	6.5	6.5	6.4	6.5	6.8	6.5	6.4	6.74

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0547	4.0556	4.0551	Cylinder 1 thru 6 ID 4.054"-4.075" Cylinder 7 thru 8 ID 4.055"-
Out of Round	0.0003	0.0011	0.0006	Maximum 0.008"
Taper	0.0000	0.0005	0.0003	
Piston Skirt Diameter	4.0494	4.0499	4.0496	
Piston Skirt to Cylinder Bore Clearance	0.0051	0.0061	0.0054	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	22.705	22.936	22.844	
Second Ring	16.931	17.029	16.962	
Oil Control Ring	15.037	15.622	15.335	
Ring To Groove Clearance				
Second Ring	0.0020	0.0020	0.0020	0.0015"-0.003"
Oil Control Ring	0.0020	0.0020	0.0020	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2211	1.2213	1.2212	1.2207"-1.2212"
Piston Pin Clearance	0.0006	0.0008	0.0007	0.0003"-0.0012"
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2214	1.2216	1.2215	1.2207"-1.2212"
Piston Pin Clearance	0.0009	0.0011	0.0010	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0025	0.0030	0.0029	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0030	0.0022	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.007	0.004-0.010"
Rod Side Clearance		Unavailable		0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0548	4.0545		0.0003
	Middle	4.0547	4.0541	4.0547	0.0006
	Bottom	4.0547	4.0544		0.0003
	Taper	0.0001	0.0004		
2	Top	4.0549	4.0546		0.0003
	Middle	4.0548	4.0541	4.0548	0.0007
	Bottom	4.0548	4.0544		0.0004
	Taper	0.0001	0.0005		
3	Top	4.0551	4.0545		0.0006
	Middle	4.0550	4.0540	4.0549	0.0010
	Bottom	4.0548	4.0544		0.0004
	Taper	0.0003	0.0005		
4	Top	4.0550	4.0545		0.0005
	Middle	4.0550	4.0540	4.0550	0.0010
	Bottom	4.0549	4.0544		0.0005
	Taper	0.0001	0.0005		
5	Top	4.0551	4.0543		0.0008
	Middle	4.0551	4.0540	4.0551	0.0011
	Bottom	4.0550	4.0545		0.0005
	Taper	0.0001	0.0005		
6	Top	4.0551	4.0544		0.0007
	Middle	4.0550	4.0540	4.0550	0.0010
	Bottom	4.0549	4.0544		0.0005
	Taper	0.0002	0.0004		
7	Top	4.0555	4.0551		0.0004
	Middle	4.0555	4.0547	4.0555	0.0008
	Bottom	4.0555	4.0550		0.0005
	Taper	0.0000	0.0004		
8	Top	4.0556	4.0551		0.0005
	Middle	4.0556	4.0547	4.0556	0.0009
	Bottom	4.0555	4.0550		0.0005
	Taper	0.0001	0.0004		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0548	4.0545		0.0003
	Middle	4.0545	4.0541	4.0545	0.0004
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0003	0.0004		
2	Top	4.0550	4.0545		0.0005
	Middle	4.0548	4.0541	4.0547	0.0007
	Bottom	4.0546	4.0545		0.0001
	Taper	0.0004	0.0004		
3	Top	4.0553	4.0545		0.0008
	Middle	4.0548	4.0540	4.0547	0.0008
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0008	0.0005		
4	Top	4.0551	4.0543		0.0008
	Middle	4.0548	4.0540	4.0547	0.0008
	Bottom	4.0545	4.0546		0.0001
	Taper	0.0006	0.0006		
5	Top	4.0551	4.0543		0.0008
	Middle	4.0549	4.0540	4.0548	0.0009
	Bottom	4.0546	4.0546		0.0000
	Taper	0.0005	0.0006		
6	Top	4.0552	4.0543		0.0009
	Middle	4.0550	4.0540	4.0550	0.0010
	Bottom	4.0549	4.0546		0.0003
	Taper	0.0003	0.0006		
7	Top	4.0555	4.0551		0.0004
	Middle	4.0554	4.0548	4.0554	0.0006
	Bottom	4.0553	4.0551		0.0002
	Taper	0.0002	0.0003		
8	Top	4.0556	4.0551		0.0005
	Middle	4.0556	4.0547	4.0553	0.0009
	Bottom	4.0550	4.0551		0.0001
	Taper	0.0006	0.0004		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0000	0.0000	
	Middle	0.0002	0.0000	0.0002
	Bottom	0.0002	0.0000	
2	Top	0.0001	0.0001	
	Middle	0.0000	0.0000	0.0001
	Bottom	0.0002	0.0001	
3	Top	0.0002	0.0000	
	Middle	0.0002	0.0000	0.0002
	Bottom	0.0003	0.0000	
4	Top	0.0001	0.0002	
	Middle	0.0002	0.0000	0.0003
	Bottom	0.0004	0.0002	
5	Top	0.0000	0.0000	
	Middle	0.0002	0.0000	0.0003
	Bottom	0.0004	0.0001	
6	Top	0.0001	0.0001	
	Middle	0.0000	0.0000	0.0000
	Bottom	0.0000	0.0002	
7	Top	0.0000	0.0000	
	Middle	0.0001	0.0001	0.0002
	Bottom	0.0002	0.0001	
8	Top	0.0000	0.0000	
	Middle	0.0000	0.0000	0.0003
	Bottom	0.0005	0.0001	
Avgerage All Cylinders	Top	0.0001	0.0001	
	Middle	0.0001	0.0000	
	Bottom	0.0003	0.0001	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3425	0.3432	0.0007	0.3724	0.3734	0.0010
2	0.3426	0.3431	0.0005	0.3724	0.3738	0.0014
3	0.3426	0.3430	0.0004	0.3724	0.3733	0.0009
4	0.3425	0.3431	0.0006	0.3724	0.3737	0.0013
5	0.3426	0.3430	0.0004	0.3725	0.3733	0.0008
6	0.3425	0.3432	0.0007	0.3724	0.3738	0.0014
7	0.3425	0.3430	0.0005	0.3724	0.3733	0.0009
8	0.3425	0.3431	0.0006	0.3725	0.3738	0.0013

Maximum	0.0007
Average	0.0005

Maximum	0.0014
Average	0.0011

Valve Stem Measurement Changes, inches

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3412	0.3410	0.0002	0.3712	0.3709	0.0003
2	0.3412	0.3409	0.0003	0.3712	0.3709	0.0003
3	0.3412	0.3410	0.0002	0.3712	0.3709	0.0003
4	0.3413	0.3410	0.0003	0.3712	0.3709	0.0003
5	0.3412	0.3410	0.0002	0.3712	0.3713	-0.0001
6	0.3412	0.3411	0.0001	0.3712	0.3712	0.0000
7	0.3413	0.3410	0.0003	0.3712	0.3712	0.0000
8	0.3412	0.3410	0.0002	0.3712	0.3712	0.0000

Maximum	0.0003
Average	0.0002

Maximum	0.0003
Average	0.0001

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance			Stem Guide Clearance		
	Intake			Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0013	0.0022	0.0009	0.0012	0.0025	0.0013
2	0.0014	0.0022	0.0008	0.0012	0.0029	0.0017
3	0.0014	0.0020	0.0006	0.0012	0.0024	0.0012
4	0.0012	0.0021	0.0009	0.0012	0.0028	0.0016
5	0.0014	0.0020	0.0006	0.0013	0.0020	0.0007
6	0.0013	0.0021	0.0008	0.0012	0.0026	0.0014
7	0.0012	0.0020	0.0008	0.0012	0.0021	0.0009
8	0.0013	0.0021	0.0008	0.0013	0.0026	0.0013

Maximum	0.0009
Average	0.0008

Maximum	0.0017
Average	0.0013

Valve Recession Measurement Changes, inches

	Valve Recession			Valve Recession		
	Intake			Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.022	0.050	0.028	0.029	0.029	0.000
2	0.028	0.047	0.019	0.023	0.052	0.029
3	0.028	0.045	0.017	0.026	0.027	0.001
4	0.023	0.049	0.026	0.027	0.028	0.001
5	0.027	0.047	0.020	0.029	0.030	0.001
6	0.023	0.050	0.027	0.027	0.026	-0.001
7	0.025	0.033	0.008	0.026	0.027	0.001
8	0.025	0.064	0.039	0.029	0.039	0.010

Maximum	0.039
Average	0.023

Maximum	0.029
Average	0.005

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	1.24
2	1.22
3	1.04
4	1.44
5	1.13
6	1.12
7	1.34
8	1.64
9	1.09
10	1.42
11	1.02
12	1.51
13	1.20
14	1.83
15	1.44
16	2.17

Maximum	2.17
Average	1.37

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0547	4.0494	0.0053
	2	4.0548	4.0495	0.0053
	3	4.0549	4.0497	0.0052
	4	4.0550	4.0496	0.0053
	5	4.0551	4.0499	0.0051
	6	4.0550	4.0497	0.0053
	7	4.0555	4.0497	0.0058
	8	4.0556	4.0495	0.0061
Post - Test	1	4.0545	4.0491	0.0054
	2	4.0547	4.0490	0.0057
	3	4.0547	4.0491	0.0056
	4	4.0547	4.0490	0.0057
	5	4.0548	4.0493	0.0055
	6	4.0550	4.0490	0.0059
	7	4.0554	4.0491	0.0062
	8	4.0553	4.0492	0.0061

Top and Second Ring Radial Wear, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.18035	0.18020	0.00015
	2	0.17975	0.17960	0.00015
	3	0.17885	0.17860	0.00025
	4	0.17815	0.17785	0.00030
	5	0.18025	0.18005	0.00020
2	1	0.18095	0.18055	0.00040
	2	0.18025	0.17995	0.00030
	3	0.17930	0.17885	0.00045
	4	0.18020	0.17995	0.00025
	5	0.18100	0.18045	0.00055
3	1	0.18040	0.18005	0.00035
	2	0.18060	0.18020	0.00040
	3	0.17980	0.17925	0.00055
	4	0.17975	0.17900	0.00075
	5	0.17950	0.17975	-0.00025
4	1	0.17980	0.18000	-0.00020
	2	0.18020	0.18005	0.00015
	3	0.18040	0.17940	0.00100
	4	0.17970	0.17900	0.00070
	5	0.17960	0.17975	-0.00015
5	1	0.17840	0.17815	0.00025
	2	0.17890	0.17875	0.00015
	3	0.17950	0.17930	0.00020
	4	0.17995	0.17980	0.00015
	5	0.17880	0.17850	0.00030
6	1	0.17955	0.17940	0.00015
	2	0.17805	0.17760	0.00045
	3	0.17975	0.17910	0.00065
	4	0.18035	0.18005	0.00030
	5	0.17980	0.17945	0.00035
7	1	0.18015	0.18125	-0.00110
	2	0.17980	0.17970	0.00010
	3	0.17830	0.17805	0.00025
	4	0.17915	0.17900	0.00015
	5	0.18005	0.17970	0.00035
8	1	0.17890	0.17850	0.00040
	2	0.17940	0.17935	0.00005
	3	0.17985	0.17945	0.00040
	4	0.17940	0.17905	0.00035
	5	0.17840	0.17825	0.00015

Maximum	0.00100
Average	0.00026

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16180	0.16135	0.00045
	2	0.16225	0.16150	0.00075
	3	0.16245	0.16165	0.00080
	4	0.16100	0.16035	0.00065
	5	0.16145	0.16085	0.00060
2	1	0.16175	0.16125	0.00050
	2	0.16160	0.16120	0.00040
	3	0.16225	0.16155	0.00070
	4	0.16170	0.16105	0.00065
	5	0.16205	0.16130	0.00075
3	1	0.16253	0.16170	0.00083
	2	0.16200	0.16165	0.00035
	3	0.16195	0.16125	0.00070
	4	0.16140	0.16070	0.00070
	5	0.16220	0.16160	0.00060
4	1	0.16240	0.16160	0.00080
	2	0.16265	0.16200	0.00065
	3	0.16155	0.16115	0.00040
	4	0.16060	0.16015	0.00045
	5	0.16210	0.16145	0.00065
5	1	0.16060	0.16020	0.00040
	2	0.16065	0.16015	0.00050
	3	0.16145	0.16075	0.00070
	4	0.16095	0.16020	0.00075
	5	0.16040	0.15985	0.00055
6	1	0.16125	0.16080	0.00045
	2	0.16070	0.16020	0.00050
	3	0.16240	0.16175	0.00065
	4	0.16170	0.16125	0.00045
	5	0.16145	0.16085	0.00060
7	1	0.16080	0.16065	0.00015
	2	0.16095	0.16065	0.00030
	3	0.16035	0.15995	0.00040
	4	0.15925	0.15860	0.00065
	5	0.16040	0.15960	0.00080
8	1	0.16135	0.16075	0.00060
	2	0.16115	0.16060	0.00055
	3	0.16135	0.16155	-0.00020
	4	0.16065	0.16005	0.00060
	5	0.16155	0.16060	0.00095

Maximum	0.00095
Average	0.00057

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.013	0.014	0.001
	2	0.033	0.037	0.004
	3	0.011	0.013	0.002
2	1	0.015	0.017	0.002
	2	0.033	0.037	0.004
	3	0.011	0.013	0.002
3	1	0.014	0.016	0.002
	2	0.033	0.038	0.005
	3	0.012	0.014	0.002
4	1	0.012	0.014	0.002
	2	0.033	0.037	0.004
	3	0.012	0.015	0.003
5	1	0.013	0.016	0.003
	2	0.033	0.045	0.012
	3	0.012	0.014	0.002
6	1	0.013	0.014	0.001
	2	0.036	0.039	0.003
	3	0.012	0.013	0.001
7	1	0.014	0.017	0.003
	2	0.034	0.045	0.011
	3	0.013	0.015	0.002
8	1	0.015	0.019	0.004
	2	0.037	0.040	0.003
	3	0.013	0.016	0.003

Ring No. 1 max increase	0.004
Ring No. 2 max increase	0.012
Ring No. 3 max increase	0.003

Ring No. 1 avg increase	0.002
Ring No. 2 avg increase	0.006
Ring No. 3 avg increase	0.002

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.705	22.662	0.0428
	2	16.955	16.937	0.0176
	3	15.378	15.366	0.0122
2	1	22.935	22.895	0.0402
	2	16.935	16.911	0.0241
	3	15.274	15.258	0.0153
3	1	22.923	22.867	0.0563
	2	16.952	16.920	0.0325
	3	15.575	15.557	0.0181
4	1	22.862	22.820	0.0413
	2	17.029	17.005	0.0244
	3	15.622	15.606	0.0153
5	1	22.826	22.765	0.0615
	2	16.943	16.916	0.0276
	3	15.037	15.021	0.0160
6	1	22.936	22.866	0.0701
	2	16.931	16.905	0.0264
	3	15.216	15.200	0.0158
7	1	22.808	22.762	0.0456
	2	16.946	16.918	0.0279
	3	15.385	15.369	0.0162
8	1	22.755	22.690	0.0642
	2	17.006	16.978	0.0272
	3	15.196	15.180	0.0161

Ring No. 1 max decrease	0.0701
Ring No. 2 max decrease	0.0325
Ring No. 3 max decrease	0.0181

Ring No. 1 avg decrease	0.0527
Ring No. 2 avg decrease	0.0260
Ring No. 3 avg decrease	0.0156

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.7097	27.6929	0.0168
	Bottom	27.7570	27.7198	0.0372
2	Top	27.7562	27.7426	0.0136
	Bottom	27.7422	27.7245	0.0177
3	Top	27.7459	27.7278	0.0181
	Bottom	27.7805	27.7644	0.0161
4	Top	27.7459	27.6943	0.0516
	Bottom	27.7592	27.7302	0.0290
5	Top	27.7347	27.7141	0.0206
	Bottom	27.8040	27.7436	0.0604
6	Top	27.7631	27.7275	0.0356
	Bottom	27.7085	27.6782	0.0303
7	Top	27.6077	27.5928	0.0149
	Bottom	27.7267	27.6782	0.0485
8	Top	27.7609	27.7374	0.0235
	Bottom	27.6907	27.6453	0.0454

Maximum	0.0604
Average	0.0300

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.1555	48.0027	0.1528
	Bottom	51.1502	51.0968	0.0534
2	Top	48.0673	47.9449	0.1224
	Bottom	51.0135	50.8177	0.1958
3	Top	96.4712	93.1742	3.2970
	Bottom	101.8524	97.0431	4.8093
4	Top	48.0922	48.0535	0.0387
	Bottom	51.0657	50.9543	0.1114
5	Top	68.7898	68.6709	0.1189
	Bottom	72.6161	72.2340	0.3821

Maximum	4.8093
Average	0.9282

<u>**Stanadyne Injection Pump Calibration/Evaluation**</u>

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 15551132**
Test condition :	

PUMP RPM	***Description***	***Spec.***	***Before***	***After***	***Change***
1000	Transfer pump psi.	60-62 psi	62	N/A	N/A
	Return Fuel	225-375 cc	340	N/A	N/A
350	Low Idle	12-16 cc	15	N/A	N/A
	Housing psi.	8-12 psi	7.5	N/A	N/A
	Advance	3.5 deg. min	4.57	N/A	N/A
	Cold Advance Solenoid	0-1 psi.	0	N/A	N/A
750	Shut-Off	4 cc max.	0	N/A	N/A
900	Fuel Delivery	66.5 - 69.5cc	68	N/A	N/A
1600	WOT Fuel delivery	59.5 min.	65	N/A	N/A
	WOT Advance	2.5 - 3.5 deg.	3.25	N/A	N/A
	Face Cam Fuel delivery	21.5 - 23.5	22	N/A	N/A
	Face Cam Advance	5.25 - 7.25 deg.	6.9	N/A	N/A
	Low Idle	11 - 12 deg.	11.03	N/A	N/A
1825	Fuel Delivery	33 cc min.	38	N/A	N/A
1950	High Idle	15 cc max.	2	N/A	N/A
	Transfer pump psi.	125 psi max.	108	N/A	N/A
200	WOT Fuel Delivery	58 cc min.	60	N/A	N/A
	WOT Shut-Off	4 cc max.	0	N/A	N/A
75	Low Idle Fuel Delivery	37 cc min.	42	N/A	N/A
	Transfer pump psi.	16 psi min.	26	N/A	N/A
	Housing psi.	0 -12 psi	6	N/A	N/A
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5	N/A	N/A

*Pump calibration data to be used for reference only
**Post test calibration check was not run do to major changes made to the roller to roller dimension on stand to maintain engine power output specified for test.

Photographs

Oil Code:	LO-257264	EOT Date:	1/24/11
Test No.:	LO257264-65T1-W-210	Test Length:	154

Piston Skirt Thrust - Best   Cyl 5

Piston Skirt Anti-thrust - Best   Cyl 5

Oil Code:	LO-257264	**EOT Date:**	1/24/11
Test No.:	LO257264-65T1-W-210	**Test Length:**	154

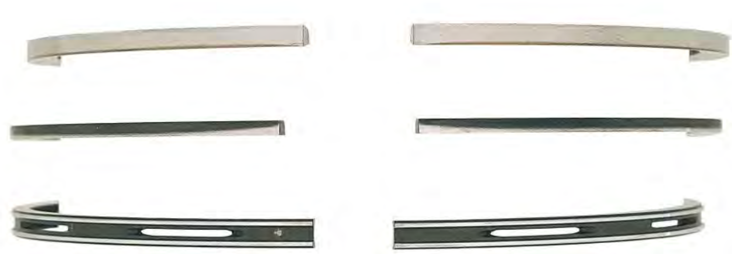
Piston Skirt Thrust - Worst Cyl 2

Piston Skirt Anti-thrust - Worst Cyl 2

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-257264	**EOT Date:**	1/24/11
Test No.:	LO257264-65T1-W-210	**Test Length:**	154

Piston Rings - Best   Cyl 1



Piston Rings - Worst   Cyl 6

Oil Code:	LO-257264	**EOT Date:**	1/24/11
Test No.:	LO257264-65T1-W-210	**Test Length:**	154

Piston Undercrown - Best Cyl 5

Piston Undercrown - Worst Cyl 2

Oil Code:	LO-257264	EOT Date:	1/24/11
Test No.:	LO257264-65T1-W-210	Test Length:	154

Engine Block Cylinder Bore - Best Cyl 1

Engine Block Cylinder Bore - Worst Cyl 6

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-257264	**EOT Date:**	1/24/11
Test No.:	LO257264-65T1-W-210	**Test Length:**	154

Exhaust and Intake Valve - Best Cyl 1

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-257264	**EOT Date:**	1/24/11
Test No.:	LO257264-65T1-W-210	**Test Length:**	154

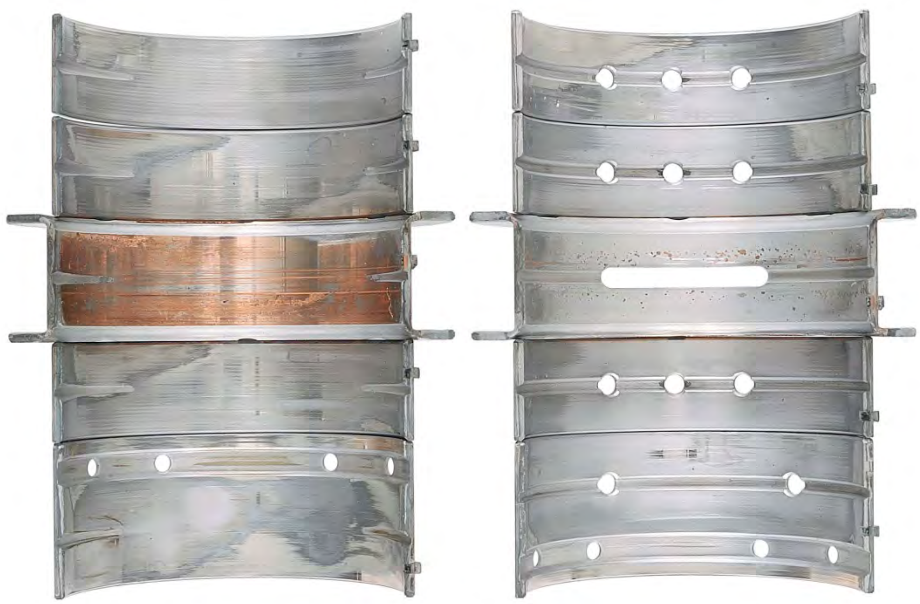
Exhaust and Intake Valve - Worst Cyl 8

Oil Code:	LO-257264	EOT Date:	1/24/11
Test No.:	LO257264-65T1-W-210	Test Length:	154

Rod Bearings

Oil Code:	LO-257264	**EOT Date:**	1/24/11
Test No.:	LO257264-65T1-W-210	**Test Length:**	154

Main Bearings



APPENDIX B3. – EVALUATION OF A COMMERCIAL PETROLEUM BASED API CJ-4 SAE 15W40 ENGINE OIL IN THE 6.5L(T) HIGH TEMPERATURE OIL ENDURANCE TEST

EVALUATION OF SCPL CANDIDATE LO-25742 COMMERCIAL PETROLUEM BASED CJ-4 15W40

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-257421
Test Fuel: Jet-A w/DCI-4A
Test Number: LO257421-65T1-W-210
Start of Test Date: November 17, 2010
End of Test Date: December 15, 2010
Test Duration: 210 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-257421 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

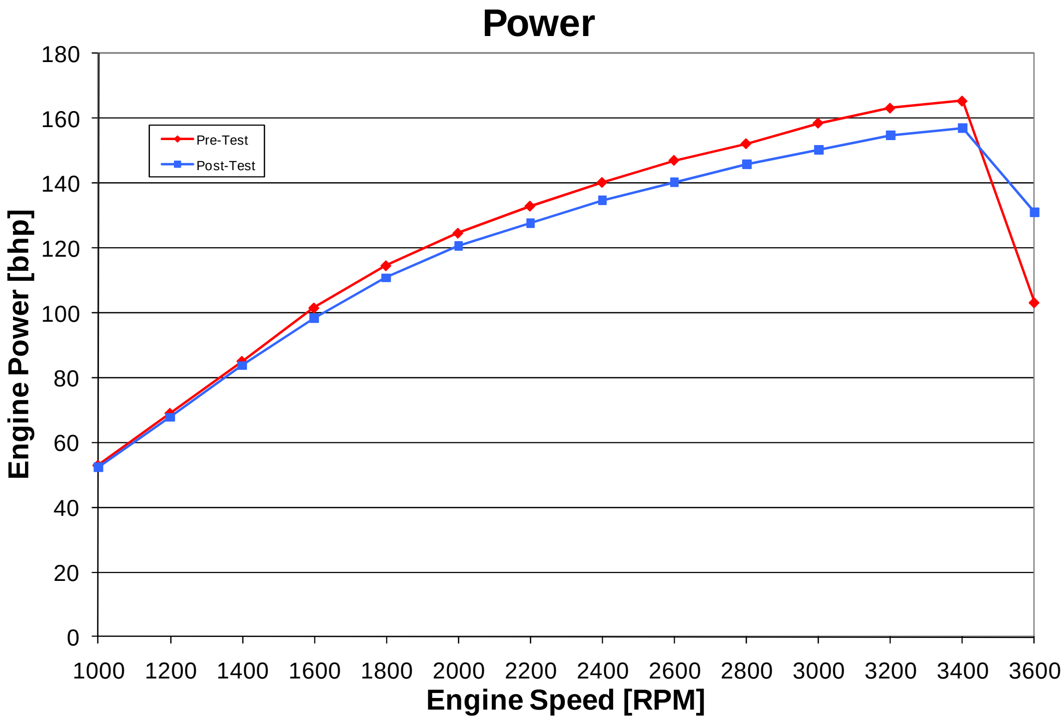
Engine Operating Conditions Summary

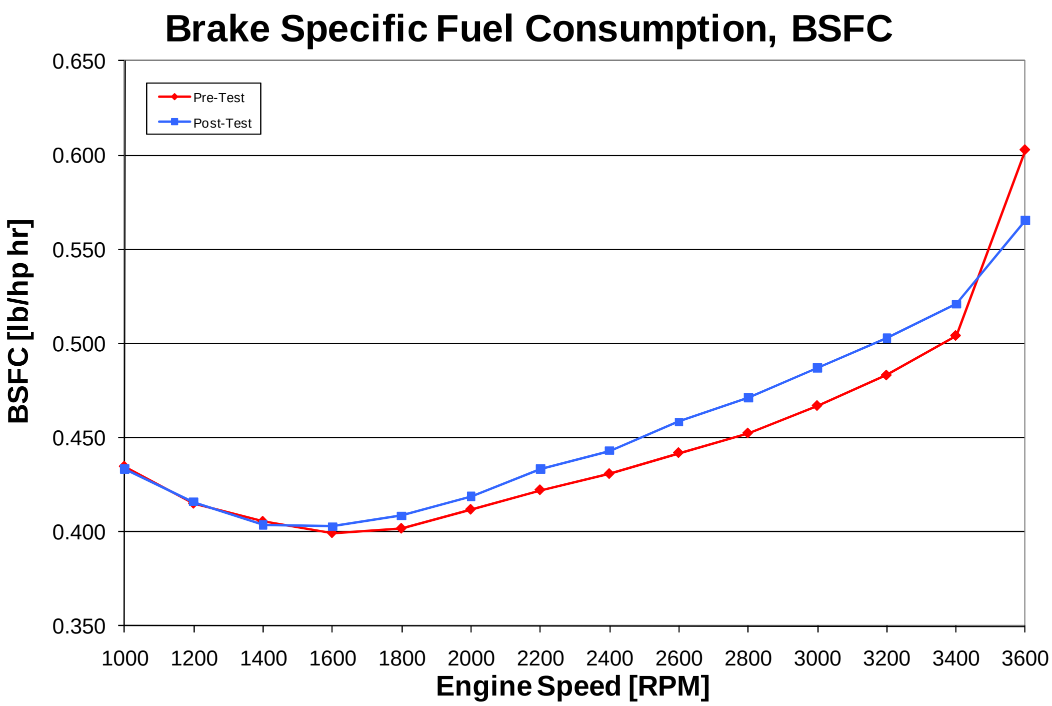
Below is a summary of the engine operating conditions over the test duration. The candidate lubricant completed the full 210 hr test duration.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.01	0.75	900.17	2.56
Torque*	ft*lb	254.83	2.32	42.26	23.31
Fuel Flow	lb/hr	80.15	1.18	6.62	1.15
Power*	bhp	164.97	1.50	7.24	4.00
BSFC*	lb/bhp*hr	0.486	0.009	1.052	0.280
Temperatures:					
Coolant In	°F	191.01	1.01	91.72	1.37
Coolant Out	°F	204.99	0.94	100.02	0.99
Oil Sump	°F	260.07	0.81	126.74	2.72
Fuel In	°F	95.01	0.34	94.99	0.31
Intake Air	°F	61.21	3.53	59.79	2.33
Cylinder 1 Exhaust	°F	1027.38	25.21	186.10	23.84
Cylinder 2 Exhaust	°F	1054.01	29.41	191.77	24.92
Cylinder 3 Exhaust	°F	1083.30	18.51	192.59	24.54
Cylinder 4 Exhaust	°F	1064.49	27.69	205.51	29.76
Cylinder 5 Exhaust	°F	1128.62	20.75	212.79	30.97
Cylinder 6 Exhaust	°F	1111.43	25.56	199.03	27.49
Cylinder 7 Exhaust	°F	1084.31	26.61	212.72	31.54
Cylinder 8 Exhaust	°F	1103.24	23.86	203.59	28.46
Pressures:					
Oil Galley	psi	45.60	1.57	50.82	0.81
Ambient Pressure	psiA	14.34	0.11	14.33	0.11
Boost Pressure	psi	5.00	0.09	-0.22	0.09

* Non-corrected Values

Engine Performance Curves

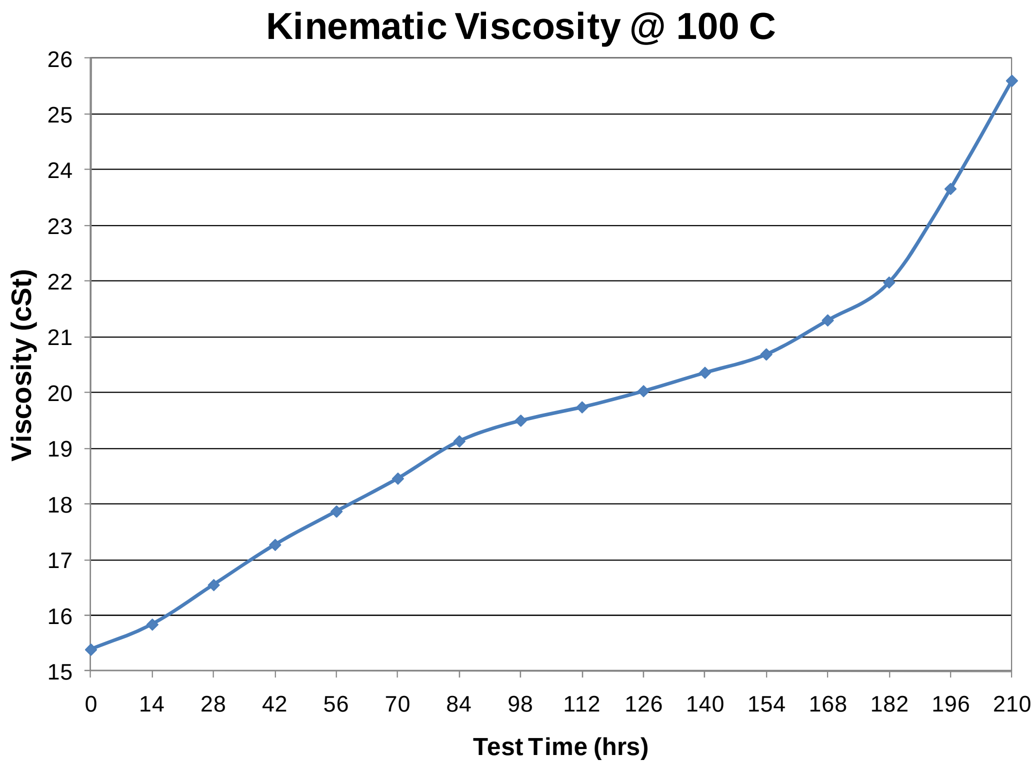


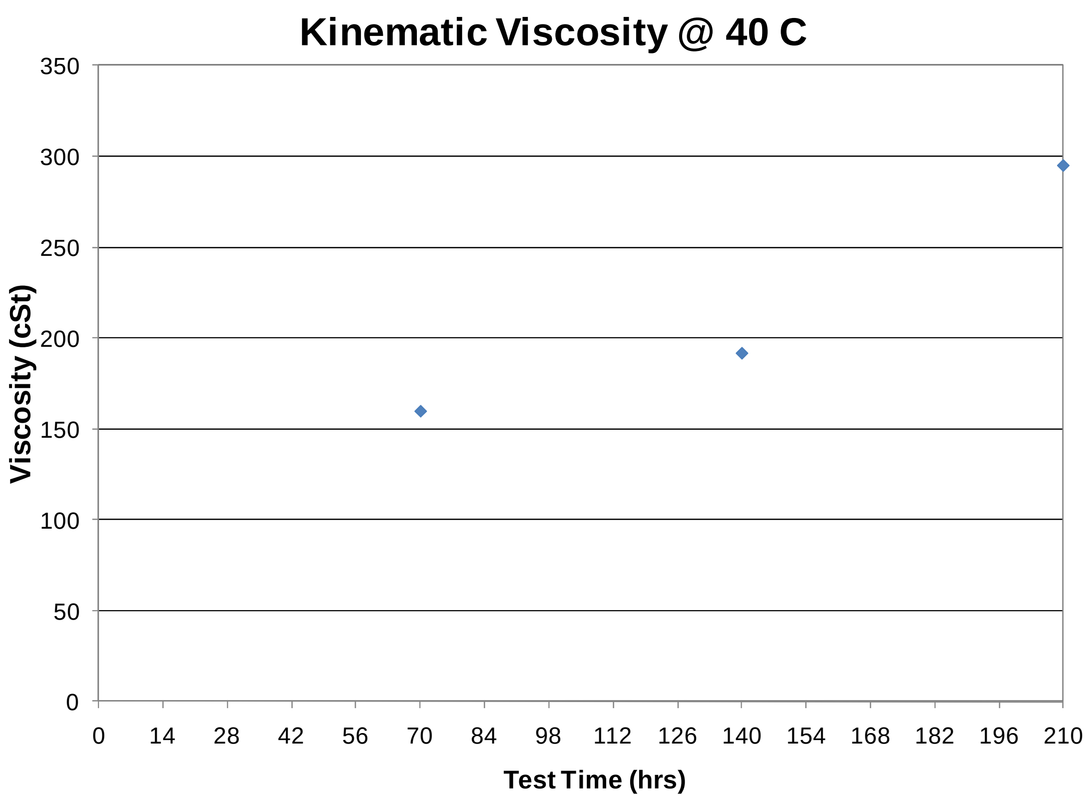


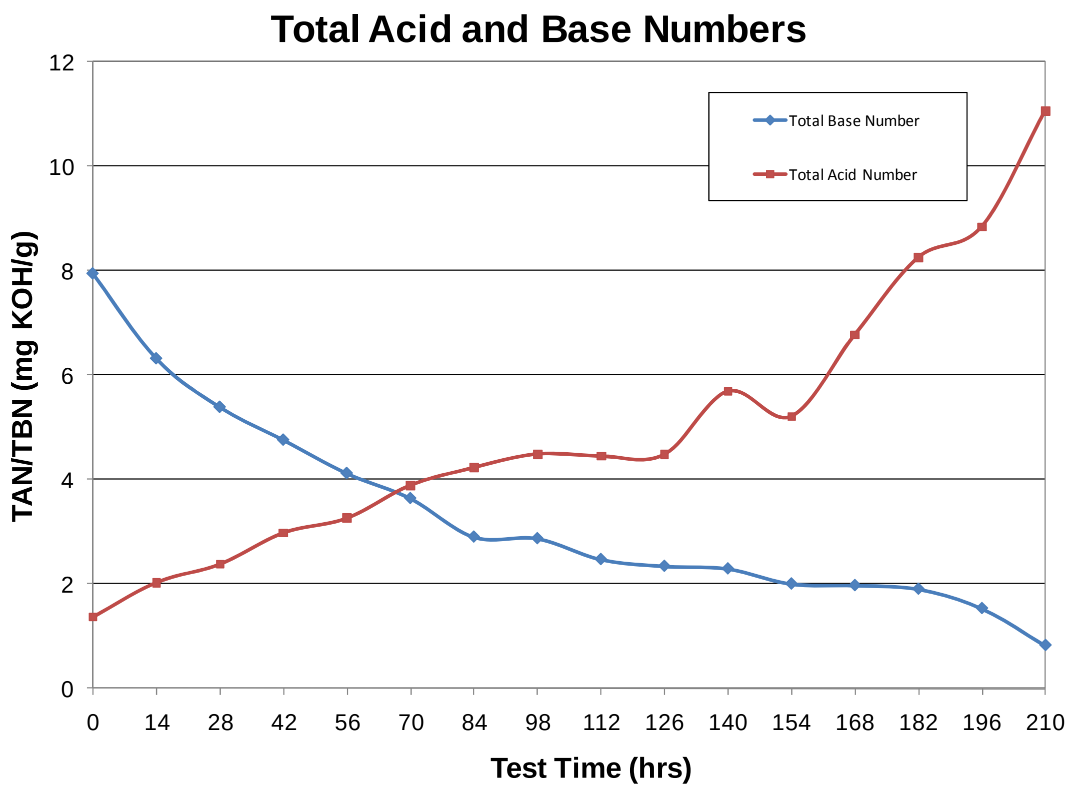
Engine Oil Analysis

Property	ASTM Test	Test Hours															
		0	14	28	42	56	70	84	98	112	126	140	154	168	182	196	210
Density	D4052	0.879	0.881	0.883	0.885	0.887	0.889	0.892	0.894	0.896	0.898	0.900	0.903	0.906	0.909	0.905	0.920
Viscosity @ 100°C (cSt)	D445	15.4	15.8	16.5	17.3	17.9	18.5	19.1	19.5	19.7	20.0	20.4	20.7	21.3	22.0	23.7	25.6
Viscosity @ 40°C (cSt)	D445						159.5					191.4					294.6
Viscosity Index (dyne/cm)	D2270						130.0					124.0					26.0
Total Base Number (mg KOH/g)	D4739	8.0	6.3	5.4	4.8	4.1	3.6	2.9	2.9	2.5	2.3	2.3	2.0	2.0	1.9	1.5	0.8
Total Acid Number (mg KOH/g)	D664	1.4	2.0	2.4	3.0	3.3	3.9	4.2	4.5	4.5	4.5	5.7	5.2	6.8	8.3	8.8	11.1
Oxidation (Abs./cm)	E168 FTNG	0.0	5.1	9.6	14.0	18.5	23.3	28.8	35.5	40.9	46.8	53.6	60.5	70.7	80.4	97.7	117.5
Nitration (Abs./cm)	E168 FTNG	0.0	3.6	3.6	4.0	4.5	6.2	8.6	11.5	13.3	16.1	20.2	24.0	28.3	31.3	36.8	39.2
Soot	Soot	0.2	0.3	0.4	0.6	0.8	0.9	1.0	1.4	1.6	1.5	1.6	1.8	2.2	2.3	2.4	2.7
Wear Metals (ppm)	D5185																
Al		<1	4	4	4	4	4	4	4	4	4	4	5	4	5	5	5
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		39	34	34	34	33	35	38	35	34	35	38	37	38	40	41	40
Ca		2239	2359	2491	2640	2710	2806	2901	3013	3103	3132	3200	3296	3245	3319	3474	3522
Cr		<1	<1	1	2	2	3	3	3	4	4	4	4	5	5	5	6
Cu		<1	12	13	15	15	16	17	19	20	20	23	26	30	38	45	65
Fe		2	51	78	105	119	132	141	154	164	175	189	198	227	256	301	355
Pb		<1	12	13	14	13	15	18	26	34	44	60	81	122	178	264	378
Mg		10	24	24	26	26	27	26	29	29	28	29	29	28	29	30	30
Mn		<1	2	2	2	2	3	3	3	3	4	4	4	4	5	5	6
Mo		1	8	11	14	15	17	18	20	20	20	21	22	22	23	23	24
Ni		<1	2	2	3	4	4	4	4	4	5	5	5	5	6	6	6
P		1048	999	959	1025	1018	1058	1075	1137	1157	1144	1212	1237	1203	1214	1289	1334
Si		5	40	48	53	53	51	49	53	51	46	48	46	45	46	44	46
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		<5	6	<5	<5	<5	<5	<5	7	<5	<5	27	7	5	7	7	8
Sn		<1	8	10	11	11	12	12	10	10	11	11	10	12	14	16	17
Zn		1174	1177	1174	1263	1314	1384	1398	1469	1553	1523	1560	1633	1584	1663	1763	1775
K		8	6	7	8	8	8	9	10	10	9	11	11	10	11	12	13
Sr		1	<1	1	1	1	<1	1	1	1	1	1	1	1	1	1	1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

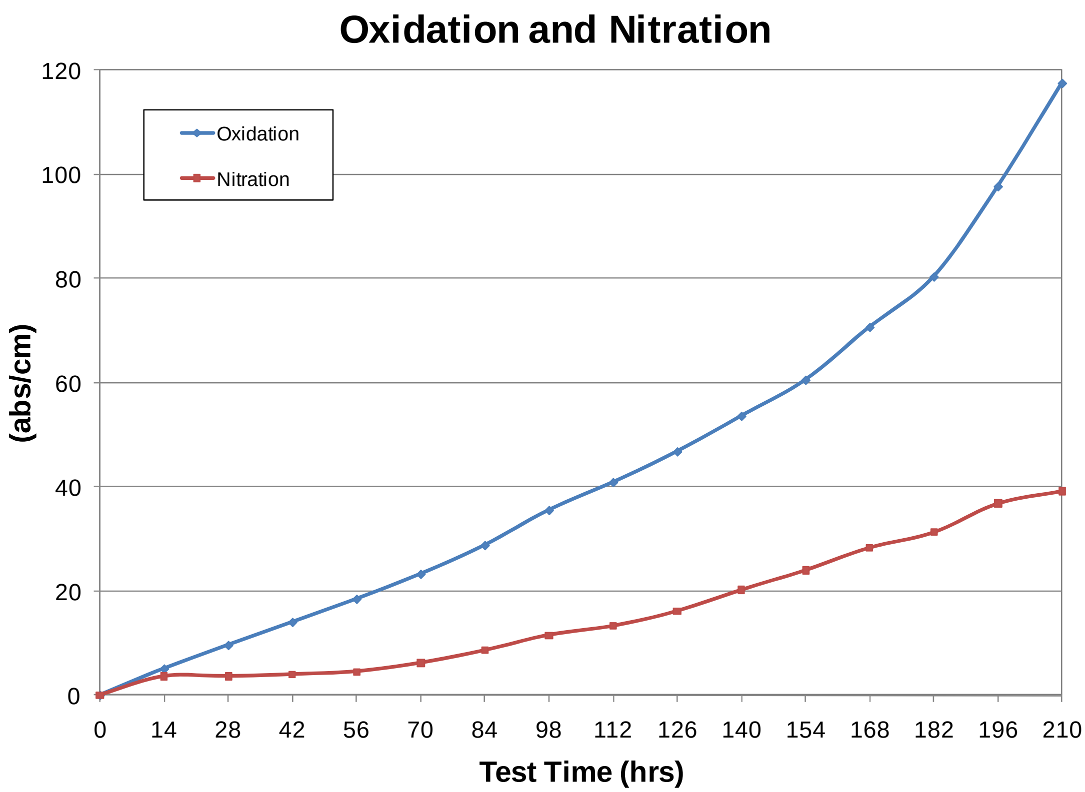
Engine Oil Analysis Trends

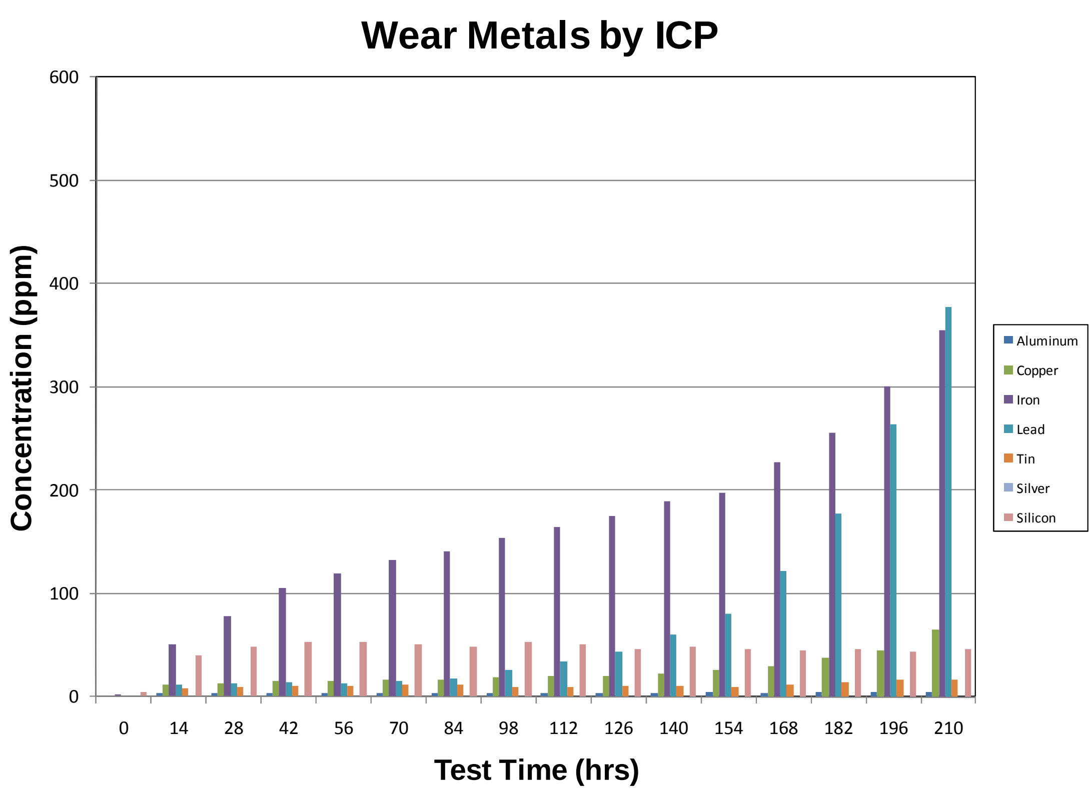





Total Acid and Base Numbers
12
10
8
6
4
2
0
TAN/TBN (mg KOH/g)
Total Base Number
Total Acid Number
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
Test Time (hrs)


Soot
3.0
2.5
2.0
1.5
1.0
0.5
0.0
(wt%)
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
Test Time (hrs)


Oxidation and Nitration
Oxidation
Nitration
(abs/cm)
0
20
40
60
80
100
120
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
Test Time (hrs)


Wear Metals by ICP
Concentration (ppm)
0
100
200
300
400
500
600
0
14
28
42
56
70
84
98
112
126
140
154
168
182
196
210
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

Oil Consumption Data

Average oil consumption per test hour was 0.090 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14 -hr	0.34	0.24	0.1	0.1
28 -hr	1.34	0.23	1.11	1.21
42 -hr	2.07	0.24	1.83	3.04
56 -hr	1.5	0.25	1.25	4.29
70 -hr	1.64	0.25	1.39	5.68
84 -hr	1.4	0.24	1.16	6.84
98 -hr	1.85	0.26	1.59	8.43
112 -hr	1.88	0.26	1.62	10.05
126 -hr	1.78	0.24	1.54	11.59
140 -hr	1.89	0.26	1.63	13.22
154 -hr	1.48	0.25	1.23	14.45
168 -hr	1.9	0.26	1.64	16.09
182 -hr	1.44	0.24	1.2	17.29
196 -hr	1.8	0.25	1.55	18.84
210 -hr	1.83	0.24	1.59	20.43
	Initial Fill	15.64	**Total Additions**	24.14
	EOT Drain	17.1	**Total Samples**	3.71

(Initial Fill + Additions)	39.78
(EOT Drain + Samples)	20.81
Total Oil Consumption	18.97

Post Test Engine Ratings

Ratings	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	No	No	No	No	No	No	No	No	--
Ring No.2	No	No	No	No	No	No	No	No	--
Ring No.3	No	No	No	No	No	No	No	No	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	48.50	73.25	69.25	65.00	50.00	40.75	66.25	60.00	59.13
No.2 Groove	6.25	1.75	29.00	6.50	12.50	13.75	18.50	15.00	12.91
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	42.75	42.00	36.00	32.75	41.75	41.75	38.50	46.75	40.28
No.2 Land	23.50	18.75	53.00	14.25	22.50	23.00	26.25	26.25	25.94
No.3 Land	1.25	0.00	3.00	3.75	0.50	2.50	1.75	1.25	1.75
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	6.25	0.00	6.25	0.00	0.00	0.00	0.00	18.75	3.91
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	3.84	5.37	0.19	1.18	2.76	1.26	0.96	2.35	2.24
No.3 Groove	0.98	2.29	1.15	2.55	1.15	2.02	1.18	1.57	1.61
No.1 Land	0.02	0.02	0.28	0.01	0.23	0.01	0.00	0.00	0.07
No.2 Land	0.22	1.05	0.22	1.22	0.49	1.47	0.44	1.07	0.77
No.3 Land	1.48	3.27	1.98	1.65	1.68	1.79	2.37	2.22	2.06
Upper Skirt	0.60	0.90	0.82	0.60	0.57	0.76	0.50	0.96	0.71
Under Crown	2.75	4.51	5.50	5.12	2.87	5.84	6.19	1.12	4.24
Front Pin Bore	1.90	1.70	0.90	0.90	1.06	1.30	1.30	1.30	1.30
Rear Pin Bore	1.90	1.30	0.90	0.90	1.06	1.30	1.30	1.30	1.25
Total, Demerits	142.19	156.16	208.44	136.38	139.12	137.50	165.49	179.89	158.15
Miscellanous									
Top Groove Fill, %	29	79	71	45	41	40	60	47	51.50
Intermediate Groove Fill, %	2	0	18	4	5	4	8	7	6.00
Top Land Heavy Carbon, %	25	24	16	11	24	23	18	29	21.25
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0	0	0.00
Valve Tulip Deposits, Merits									
Exahust	8.9	9.0	9.0	9.0	9.1	9.0	8.9	9.2	9.01
Intake	7.4	7.2	7.2	6.7	7.4	7.2	7.4	7.2	7.21

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0548	4.0556	4.0551	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0000	0.0012	0.0006	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0000	0.0006	0.0003	
Piston Skirt Diameter	4.0494	4.0499	4.0496	
Piston Skirt to Cylinder Bore Clearance	0.0050	0.0060	0.0055	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.010	0.013	0.011	
Second Ring	0.029	0.038	0.032	
Oil Control Ring	0.010	0.012	0.010	
Ring To Groove Clearance				
Second Ring	0.0020	0.0020	0.0020	0.0015"-0.003"
Oil Control Ring	0.0020	0.0020	0.0020	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2213	1.2214	1.2213	1.2207"-1.2212"
Piston Pin Clearance	0.0008	0.0009	0.0008	0.0003"-0.0012"
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2213	1.2217	1.2215	1.2207"-1.2212"
Piston Pin Clearance	0.0008	0.0012	0.0010	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0025	0.0030	0.0028	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0030	0.0022	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.006	0.004-0.010"
Rod Side Clearance	0.016	0.016	0.016	0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0548	4.0548		0.0000
	Middle	4.0548	4.0544	4.0548	0.0004
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0000	0.0004		
2	Top	4.0549	4.0547		0.0002
	Middle	4.0549	4.0542	4.0549	0.0007
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0001	0.0005		
3	Top	4.0551	4.0544		0.0007
	Middle	4.0550	4.0541	4.0548	0.0009
	Bottom	4.0545	4.0545		0.0000
	Taper	0.0006	0.0004		
4	Top	4.0550	4.0545		0.0005
	Middle	4.0550	4.0541	4.0550	0.0009
	Bottom	4.0550	4.0545		0.0005
	Taper	0.0000	0.0004		
5	Top	4.0550	4.0544		0.0006
	Middle	4.0550	4.0540	4.0550	0.0010
	Bottom	4.0550	4.0545		0.0005
	Taper	0.0000	0.0005		
6	Top	4.0550	4.0544		0.0006
	Middle	4.0550	4.0540	4.0550	0.0010
	Bottom	4.0549	4.0545		0.0004
	Taper	0.0001	0.0005		
7	Top	4.0554	4.0552		0.0002
	Middle	4.0555	4.0547	4.0555	0.0008
	Bottom	4.0555	4.0550		0.0005
	Taper	0.0001	0.0005		
8	Top	4.0555	4.0550		0.0005
	Middle	4.0556	4.0544	4.0556	0.0012
	Bottom	4.0555	4.0549		0.0006
	Taper	0.0001	0.0006		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0551	4.0545		0.0006
	Middle	4.0549	4.0542	4.0549	0.0007
	Bottom	4.0549	4.0547		0.0002
	Taper	0.0002	0.0005		
2	Top	4.0551	4.0545		0.0006
	Middle	4.0549	4.0542	4.0549	0.0007
	Bottom	4.0548	4.0546		0.0002
	Taper	0.0003	0.0004		
3	Top	4.0553	4.0542		0.0011
	Middle	4.0550	4.0540	4.0549	0.0010
	Bottom	4.0547	4.0545		0.0002
	Taper	0.0006	0.0005		
4	Top	4.0550	4.0545		0.0005
	Middle	4.0550	4.0541	4.0549	0.0009
	Bottom	4.0548	4.0547		0.0001
	Taper	0.0002	0.0006		
5	Top	4.0552	4.0542		0.0010
	Middle	4.0550	4.0540	4.0549	0.0010
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0004	0.0005		
6	Top	4.0553	4.0548		0.0005
	Middle	4.0550	4.0540	4.0549	0.0010
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0005	0.0008		
7	Top	4.0556	4.0550		0.0006
	Middle	4.0554	4.0546	4.0553	0.0008
	Bottom	4.0551	4.0550		0.0001
	Taper	0.0005	0.0004		
8	Top	4.0556	4.0551		0.0005
	Middle	4.0556	4.0546	4.0555	0.0010
	Bottom	4.0553	4.0551		0.0002
	Taper	0.0003	0.0005		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0003	0.0003	
	Middle	0.0001	0.0002	0.0001
	Bottom	0.0001	0.0002	
2	Top	0.0002	0.0002	
	Middle	0.0000	0.0000	0.0000
	Bottom	0.0000	0.0001	
3	Top	0.0002	0.0002	
	Middle	0.0000	0.0001	0.0001
	Bottom	0.0002	0.0000	
4	Top	0.0000	0.0000	
	Middle	0.0000	0.0000	0.0001
	Bottom	0.0002	0.0002	
5	Top	0.0002	0.0002	
	Middle	0.0000	0.0000	0.0001
	Bottom	0.0002	0.0000	
6	Top	0.0003	0.0004	
	Middle	0.0000	0.0000	0.0000
	Bottom	0.0001	0.0000	
7	Top	0.0002	0.0002	
	Middle	0.0001	0.0001	0.0003
	Bottom	0.0004	0.0000	
8	Top	0.0001	0.0001	
	Middle	0.0000	0.0002	0.0001
	Bottom	0.0002	0.0002	
Avgerage All Cylinders	Top	0.0002	0.0002	
	Middle	0.0000	0.0001	
	Bottom	0.0002	0.0001	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3426	0.3428	0.0002	0.3724	0.3736	0.0012
2	0.3425	0.3427	0.0002	0.3724	0.3735	0.0011
3	0.3426	0.3430	0.0004	0.3724	0.3745	0.0021
4	0.3426	0.3429	0.0003	0.3725	0.3732	0.0007
5	0.3425	0.3429	0.0004	0.3725	0.3735	0.0010
6	0.3426	0.3428	0.0002	0.3724	0.3735	0.0011
7	0.3426	0.3430	0.0004	0.3724	0.3738	0.0014
8	0.3425	0.3427	0.0002	0.3725	0.3731	0.0006

	Intake		Exhaust
Maximum	0.0004	Maximum	0.0021
Average	0.0003	Average	0.0011

Valve Stem Measurement Changes, inches

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3412	0.3411	0.0001	0.3712	0.3710	0.0002
2	0.3412	0.3412	0.0000	0.3712	0.3711	0.0001
3	0.3413	0.3412	0.0001	0.3712	0.3711	0.0001
4	0.3413	0.3410	0.0003	0.3712	0.3711	0.0001
5	0.3412	0.3411	0.0001	0.3712	0.3710	0.0002
6	0.3412	0.3411	0.0001	0.3712	0.3710	0.0002
7	0.3413	0.3411	0.0002	0.3712	0.3710	0.0002
8	0.3412	0.3411	0.0001	0.3712	0.3711	0.0001

Maximum	0.0003	Maximum	0.0002
Average	0.0001	Average	0.0001

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance			Stem Guide Clearance		
	Intake			Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0014	0.0017	0.0003	0.0012	0.0026	0.0014
2	0.0013	0.0015	0.0002	0.0012	0.0024	0.0012
3	0.0013	0.0018	0.0005	0.0012	0.0034	0.0022
4	0.0013	0.0019	0.0006	0.0013	0.0021	0.0008
5	0.0013	0.0018	0.0005	0.0013	0.0025	0.0012
6	0.0014	0.0017	0.0003	0.0012	0.0025	0.0013
7	0.0013	0.0019	0.0006	0.0012	0.0028	0.0016
8	0.0013	0.0016	0.0003	0.0013	0.0020	0.0007

Maximum	0.0006
Average	0.0004

Maximum	0.0022
Average	0.0013

Valve Recession Measurement Changes, inches

	Valve Recession			Valve Recession		
	Intake			Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.022	0.047	0.025	0.023	0.054	0.031
2	0.024	0.035	0.011	0.026	0.048	0.022
3	0.021	0.041	0.020	0.024	0.036	0.012
4	0.025	0.040	0.015	0.025	0.049	0.024
5	0.022	0.049	0.027	0.022	0.033	0.011
6	0.019	0.041	0.022	0.023	0.027	0.004
7	0.022	0.046	0.024	0.024	0.038	0.014
8	0.025	0.046	0.021	0.026	0.034	0.008

Maximum	0.027
Average	0.021

Maximum	0.031
Average	0.016

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	2.00
2	2.15
3	1.39
4	1.72
5	1.54
6	1.98
7	1.38
8	1.27
9	1.56
10	1.57
11	1.28
12	1.28
13	1.80
14	1.89
15	1.75
16	1.28

Maximum	2.15
Average	1.62

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0548	4.0495	0.0053
	2	4.0549	4.0494	0.0054
	3	4.0548	4.0496	0.0052
	4	4.0550	4.0496	0.0054
	5	4.0550	4.0494	0.0056
	6	4.0550	4.0499	0.0050
	7	4.0555	4.0495	0.0060
	8	4.0556	4.0496	0.0060
Post - Test	1	4.0549	4.0495	0.0054
	2	4.0549	4.0491	0.0057
	3	4.0549	4.0496	0.0053
	4	4.0549	4.0494	0.0055
	5	4.0549	4.0491	0.0058
	6	4.0549	4.0499	0.0050
	7	4.0553	4.0493	0.0060
	8	4.0555	4.0496	0.0059

Top and Second Ring Radial Wear, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.17785	0.17740	0.00045
	2	0.17760	0.17705	0.00055
	3	0.17920	0.17875	0.00045
	4	0.17865	0.17830	0.00035
	5	0.17840	0.17795	0.00045
2	1	0.18070	0.18035	0.00035
	2	0.18005	0.17965	0.00040
	3	0.17845	0.17800	0.00045
	4	0.17745	0.17695	0.00050
	5	0.18035	0.18030	0.00005
3	1	0.17845	0.17810	0.00035
	2	0.17965	0.17940	0.00025
	3	0.18045	0.17995	0.00050
	4	0.17765	0.17760	0.00005
	5	0.17780	0.17755	0.00025
4	1	0.17725	0.17665	0.00060
	2	0.17530	0.17495	0.00035
	3	0.17745	0.17715	0.00030
	4	0.17975	0.17900	0.00075
	5	0.17770	0.17730	0.00040
5	1	0.17885	0.17835	0.00050
	2	0.17810	0.17760	0.00050
	3	0.17845	0.17805	0.00040
	4	0.17870	0.17825	0.00045
	5	0.18000	0.17960	0.00040
6	1	0.17950	0.17905	0.00045
	2	0.17850	0.17780	0.00070
	3	0.17885	0.17830	0.00055
	4	0.17925	0.17870	0.00055
	5	0.18010	0.17965	0.00045
7	1	0.17690	0.17675	0.00015
	2	0.17795	0.17755	0.00040
	3	0.18040	0.17995	0.00045
	4	0.17955	0.17915	0.00040
	5	0.17875	0.17855	0.00020
8	1	0.17705	0.17675	0.00030
	2	0.17535	0.17480	0.00055
	3	0.17605	0.17575	0.00030
	4	0.17955	0.17935	0.00020
	5	0.17780	0.17750	0.00030

Maximum	0.00075
Average	0.00040

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16280	0.16190	0.00090
	2	0.16175	0.16115	0.00060
	3	0.16155	0.16085	0.00070
	4	0.16950	0.16120	0.00830
	5	0.16280	0.16190	0.00090
2	1	0.16330	0.16245	0.00085
	2	0.16215	0.16165	0.00050
	3	0.16210	0.16110	0.00100
	4	0.16225	0.16150	0.00075
	5	0.16285	0.16220	0.00065
3	1	0.16330	0.16190	0.00140
	2	0.16140	0.16065	0.00075
	3	0.16095	0.15985	0.00110
	4	0.16175	0.16090	0.00085
	5	0.16270	0.16165	0.00105
4	1	0.16250	0.16160	0.00090
	2	0.16180	0.16095	0.00085
	3	0.16115	0.16025	0.00090
	4	0.16140	0.16085	0.00055
	5	0.16235	0.16135	0.00100
5	1	0.16400	0.16365	0.00035
	2	0.16375	0.16300	0.00075
	3	0.16330	0.16255	0.00075
	4	0.16300	0.16235	0.00065
	5	0.16340	0.16275	0.00065
6	1	0.16280	0.16170	0.00110
	2	0.16155	0.16065	0.00090
	3	0.16155	0.16015	0.00140
	4	0.16175	0.16095	0.00080
	5	0.16245	0.16140	0.00105
7	1	0.16245	0.16160	0.00085
	2	0.16180	0.16065	0.00115
	3	0.16130	0.16005	0.00125
	4	0.16150	0.16065	0.00085
	5	0.16235	0.16135	0.00100
8	1	0.16205	0.16120	0.00085
	2	0.16180	0.16135	0.00045
	3	0.16135	0.16050	0.00085
	4	0.16150	0.16070	0.00080
	5	0.16190	0.16105	0.00085

Maximum	0.00830
Average	0.00105

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.010	0.014	0.004
	2	0.029	0.035	0.006
	3	0.010	0.010	0.000
2	1	0.010	0.013	0.003
	2	0.029	0.035	0.006
	3	0.010	0.012	0.002
3	1	0.010	0.014	0.004
	2	0.029	0.035	0.006
	3	0.010	0.010	0.000
4	1	0.011	0.014	0.003
	2	0.036	0.035	-0.001
	3	0.010	0.010	0.000
5	1	0.010	0.014	0.004
	2	0.038	0.039	0.001
	3	0.010	0.010	0.000
6	1	0.010	0.014	0.004
	2	0.029	0.035	0.006
	3	0.010	0.011	0.001
7	1	0.013	0.017	0.004
	2	0.036	0.037	0.001
	3	0.010	0.013	0.003
8	1	0.012	0.017	0.005
	2	0.031	0.042	0.011
	3	0.012	0.014	0.002

Ring No. 1 max increase	0.005
Ring No. 2 max increase	0.011
Ring No. 3 max increase	0.003

Ring No. 1 avg increase	0.004
Ring No. 2 avg increase	0.005
Ring No. 3 avg increase	0.001

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.5251	22.4743	0.0508
	2	17.2019	17.1794	0.0225
	3	15.0272	15.0137	0.0135
2	1	22.5672	22.5151	0.0521
	2	17.2946	17.2648	0.0298
	3	15.1516	15.1349	0.0167
3	1	22.8376	22.7795	0.0581
	2	17.0851	17.0504	0.0347
	3	15.0938	15.0746	0.0192
4	1	22.4726	22.4185	0.0541
	2	17.2045	17.1791	0.0254
	3	15.2446	15.2278	0.0168
5	1	22.4754	22.4127	0.0627
	2	17.4550	17.4247	0.0303
	3	15.0231	15.0057	0.0174
6	1	22.6359	22.5557	0.0802
	2	17.1847	17.1499	0.0348
	3	15.0069	14.9855	0.0214
7	1	22.6189	22.5659	0.0530
	2	17.1968	17.1745	0.0223
	3	15.1007	15.0861	0.0146
8	1	22.6825	22.6286	0.0539
	2	17.1730	17.1431	0.0299
	3	15.0701	15.0497	0.0204

Ring No. 1 max decrease	0.0802
Ring No. 2 max decrease	0.0348
Ring No. 3 max decrease	0.0214

Ring No. 1 avg decrease	0.0581
Ring No. 2 avg decrease	0.0287
Ring No. 3 avg decrease	0.0175

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.7520	27.7365	0.0155
	Bottom	27.7449	27.7250	0.0199
2	Top	27.6672	27.6386	0.0286
	Bottom	27.7042	27.6843	0.0199
3	Top	27.7217	27.6965	0.0252
	Bottom	27.7501	27.7322	0.0179
4	Top	27.7212	27.6991	0.0221
	Bottom	27.7292	27.7088	0.0204
5	Top	27.6500	27.6292	0.0208
	Bottom	27.7061	27.6927	0.0134
6	Top	27.6609	27.6445	0.0164
	Bottom	27.7155	27.6981	0.0174
7	Top	27.7123	27.6943	0.0180
	Bottom	27.7427	27.7191	0.0236
8	Top	27.7566	27.7366	0.0200
	Bottom	27.7503	27.7312	0.0191

Maximum	0.0286
Average	0.0199

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	47.6520	47.4312	0.2208
	Bottom	51.8055	51.7539	0.0516
2	Top	47.5870	47.4605	0.1265
	Bottom	51.6964	51.6322	0.0642
3	Top	97.2114	95.4155	1.7959
	Bottom	102.8243	101.8407	0.9836
4	Top	47.7967	47.7068	0.0899
	Bottom	51.9047	51.8554	0.0493
5	Top	68.3177	68.2505	0.0672
	Bottom	72.4016	72.3206	0.0810

Maximum	1.7959
Average	0.3530

Stanadyne Injection Pump Calibration/Evaluation

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 15474653**
Test condition :	**AL:**

PUMP RPM	*Description*	*Spec.*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60-62 psi	62	61	1
	Return Fuel	225-375 cc	270	330	60
350	Low Idle	12-16 cc	14	9	5
	Housing psi.	8-12 psi	8	9.5	1.5
	Advance	3.5 deg. min	5.15	5.57	0.42
	Cold Advance Solenoid	0-1 psi.	0	0.5	0.5
750	Shut-Off	4 cc max.	0	0	0
900	Fuel Delivery	66.5 - 69.5cc	67	67	0
1600	WOT Fuel delivery	59.5 min.	64	63	1
	WOT Advance	2.5 - 3.5 deg.	3.03	3.08	0.05
	Face Cam Fuel delivery	21.5 - 23.5	22	22	0
	Face Cam Advance	5.25 - 7.25 deg.	7.01	6.81	0.2
	Low Idle	11 - 12 deg.	11	11.11	0.11
1825	Fuel Delivery	33 cc min.	38	37	1
1950	High Idle	15 cc max.	1	0.5	0.5
	Transfer pump psi.	125 psi max.	100	99	1
200	WOT Fuel Delivery	58 cc min.	63	62	1
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	58	52	6
	Transfer pump psi.	16 psi min.	30	29	1
	Housing psi.	0 -12 psi	5	9	4
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5	-	
	Fluid Temp. Deg. C				
	Date				

*Pump calibration data to be used for reference only

Photographs

Oil Code:	LO-257421	**EOT Date:**	11/17/10
Test No.:	LO257421-65T1-W-210	**Test Length:**	210

Piston Skirt Thrust - Best Cyl 4

Piston Skirt Anti-thrust - Best Cyl 4

Oil Code:	LO-257421	**EOT Date:**	11/17/10
Test No.:	LO257421-65T1-W-210	**Test Length:**	210

Piston Skirt Thrust - Worst Cyl 3

Piston Skirt Anti-thrust - Worst Cyl 3

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-257421	**EOT Date:**	11/17/10
Test No.:	LO257421-65T1-W-210	**Test Length:**	210

Piston Rings - Best Cyl 1

Piston Rings - Worst Cyl 6

Oil Code:	LO-257421	EOT Date:	11/17/10
Test No.:	LO257421-65T1-W-210	Test Length:	210

Piston Undercrown - Best Cyl 4

Piston Undercrown - Worst Cyl 3

Oil Code:	LO-257421	EOT Date:	11/17/10
Test No.:	LO257421-65T1-W-210	Test Length:	210

Engine Block Cylinder Bore - Best Cyl 2

Engine Block Cylinder Bore - Worst Cyl 3

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-257421	**EOT Date:**	11/17/10
Test No.:	LO257421-65T1-W-210	**Test Length:**	210

Exhaust and Intake Valve - Best Cyl 5

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-257421	EOT Date:	11/17/10
Test No.:	LO257421-65T1-W-210	Test Length:	210

Exhaust and Intake Valve - Worst Cyl 4

Oil Code:	LO-257421	**EOT Date:**	11/17/10
Test No.:	LO257421-65T1-W-210	**Test Length:**	210

Rod Bearings

Oil Code:	LO-257421	EOT Date:	11/17/10
Test No.:	LO257421-65T1-W-210	Test Length:	210

Main Bearings

APPENDIX C1. – EVALUATION OF LO253071 IN THE 6.5L(T) HIGH TEMPERATURE OIL ENDURANCE TEST

EVALUATION OF SCPL CANDIDATE LO-253071

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-253071
Test Fuel: Jet-A w/DCI-4A
Test Number: LO253071-65T1-W-210
Start of Test Date: September 9, 2010
End of Test Date: September 20, 2010
Test Duration: 126 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-253071 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

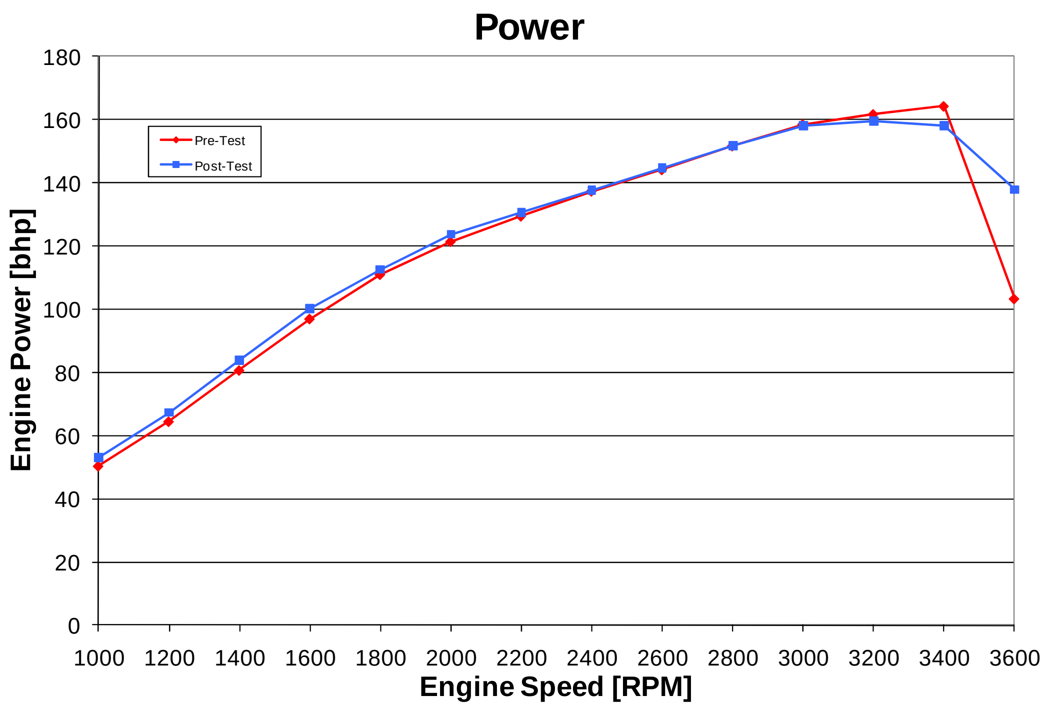
Engine Operating Conditions Summary

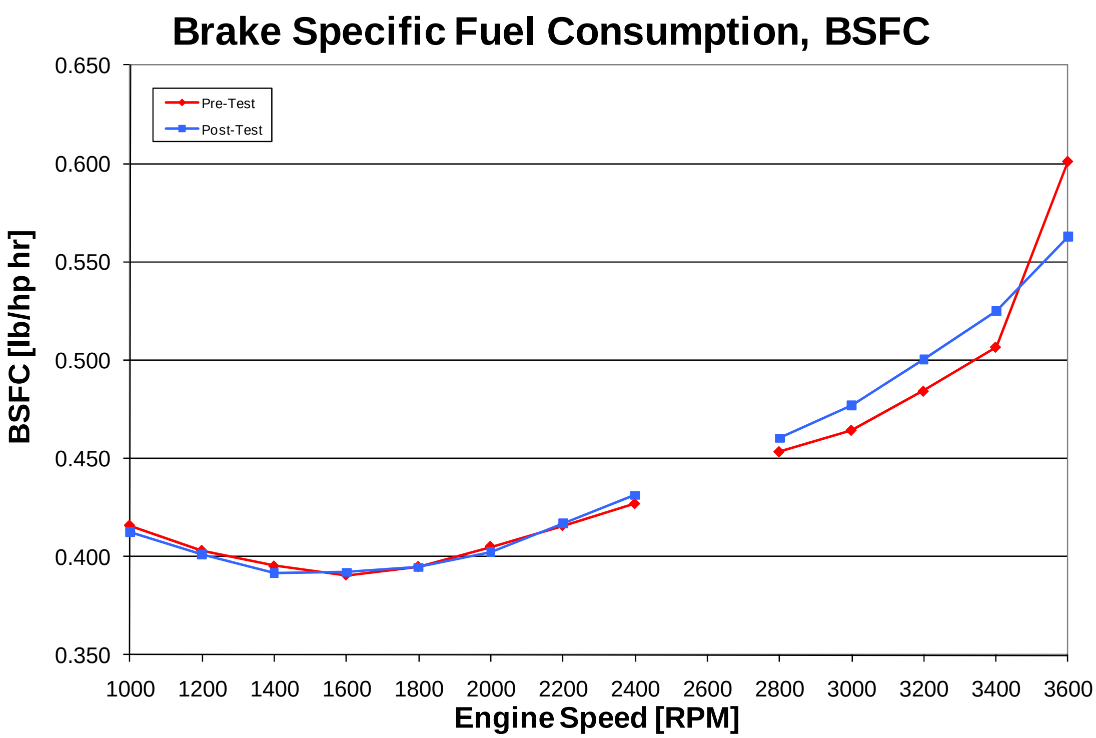
Below is a summary of the engine operating conditions over the test duration. Testing was stopped at 126 hrs due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.02	0.82	900.15	1.55
Torque*	ft*lb	251.40	4.43	49.67	28.67
Fuel Flow	lb/hr	82.51	1.06	6.14	1.68
Power*	bhp	162.74	2.87	8.51	4.92
BSFC*	lb/bhp*hr	0.507	0.012	0.760	0.097
Temperatures:					
Coolant In	°F	190.31	0.92	91.86	1.12
Coolant Out	°F	205.00	0.84	100.13	2.05
Oil Sump	°F	260.02	0.41	125.73	3.86
Fuel In	°F	95.00	0.31	94.99	0.33
Intake Air	°F	69.72	4.99	64.15	4.54
Cylinder 1 Exhaust	°F	1148.60	9.38	201.44	49.43
Cylinder 2 Exhaust	°F	1104.56	14.95	198.31	44.36
Cylinder 3 Exhaust	°F	1216.91	13.84	212.57	51.78
Cylinder 4 Exhaust	°F	1158.22	17.08	214.67	53.87
Cylinder 5 Exhaust	°F	1173.29	9.48	215.66	49.51
Cylinder 6 Exhaust	°F	1206.17	21.87	209.90	58.13
Cylinder 7 Exhaust	°F	1133.30	10.52	204.68	48.76
Cylinder 8 Exhaust	°F	1189.49	23.12	206.28	56.95
Pressures:					
Oil Galley	psi	34.70	0.74	33.80	4.20
Ambient Pressure	psiA	14.25	0.05	14.24	0.05
Boost Pressure	psi	4.95	0.11	-0.10	0.15

* Non-corrected Values

Engine Performance Curves



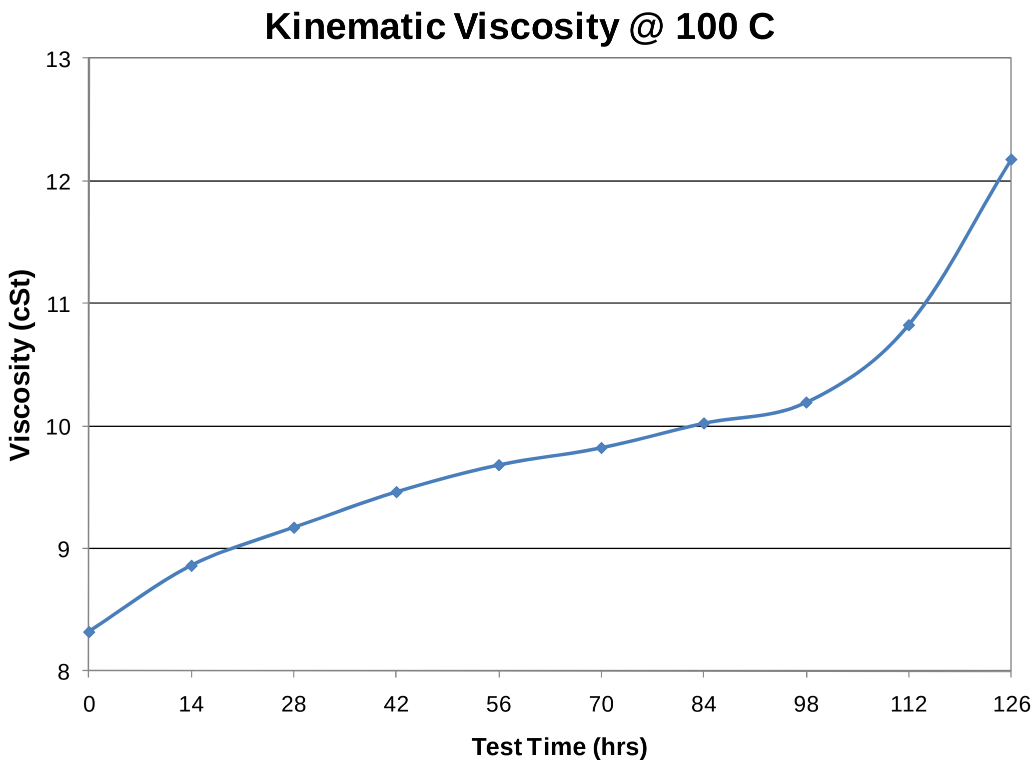


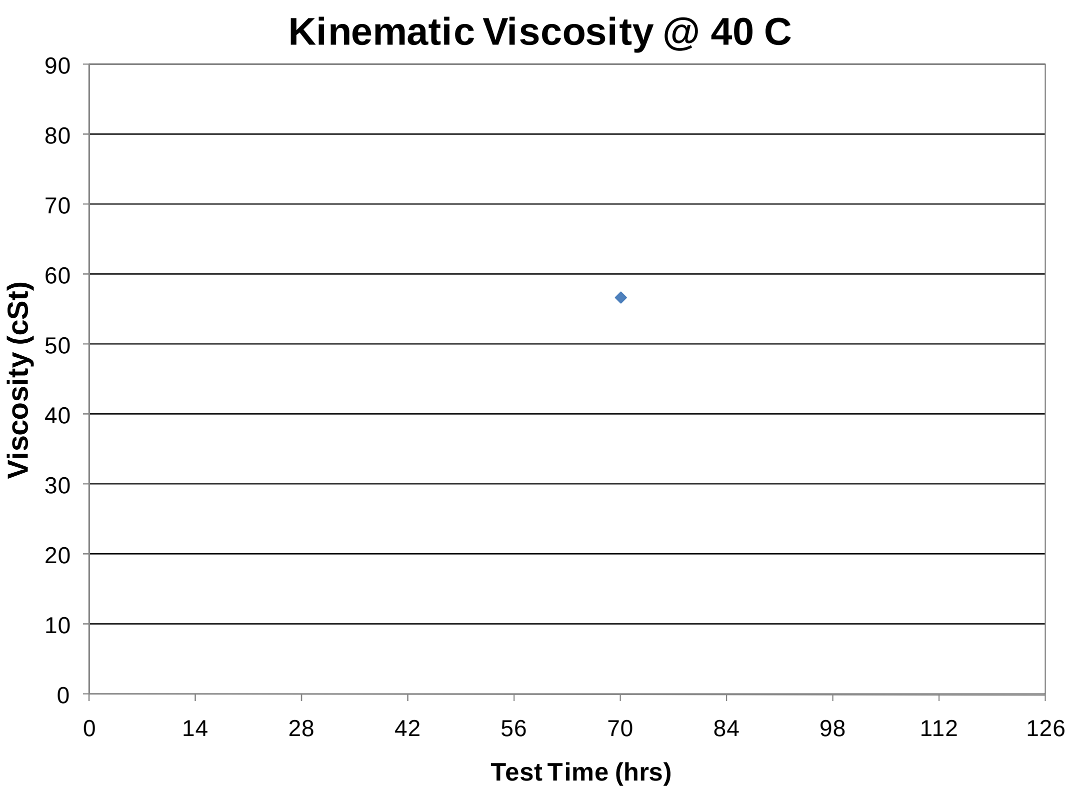
*Note – Breaks in BSFC plot due to invalid values for engine fuel flow during powercurve.

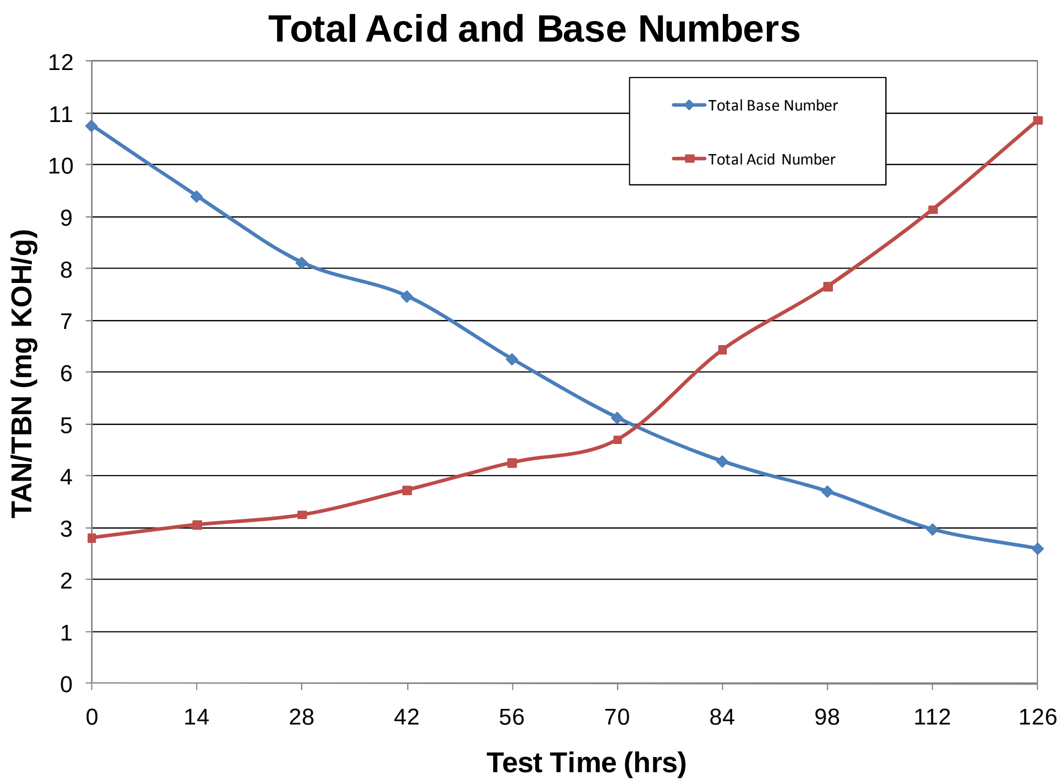
Engine Oil Analysis

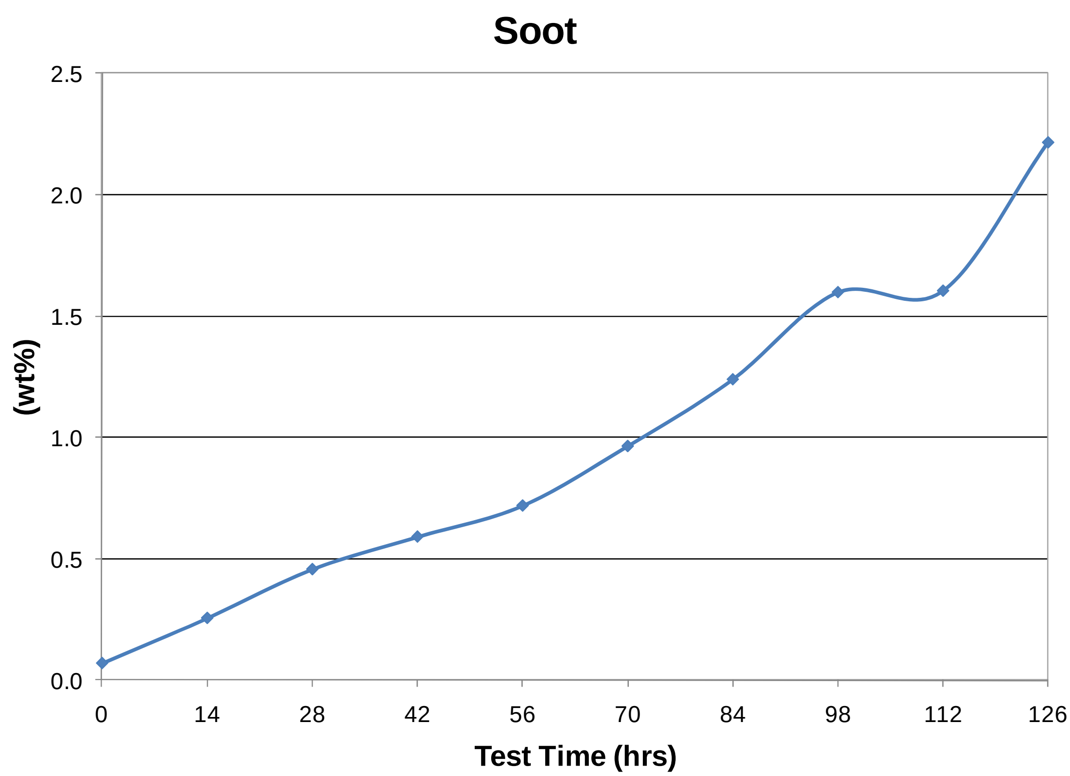
Property	ASTM Test	Test Hours									
		0	14	28	42	56	70	84	98	112	126
Density	D4052	0.8519	0.8548	0.8575	0.8602	0.863	0.8663	0.87	0.8761	0.8857	0.896
Viscosity @ 100°C (cSt)	D445	8.3	8.9	9.2	9.5	9.7	9.8	10.0	10.2	10.8	12.2
Viscosity @ 40°C (cSt)	D445						56.8				
Viscosity Index (dyne/cm)	D2270						160.0				
Total Base Number (mg KOH/g)	D4739	10.8	9.4	8.1	7.5	6.3	5.1	4.3	3.7	3.0	2.6
Total Acid Number (mg KOH/g)	D664	2.8	3.1	3.3	3.7	4.3	4.7	6.4	7.7	9.1	10.9
Oxidation (Abs./cm)	E168 FTNG	0.0	5.5	12.1	18.8	25.3	34.0	43.7	63.7	100.4	136.7
Nitration (Abs./cm)	E168 FTNG	0.0	9.2	12.1	11.3	14.7	22.6	33.4	54.1	70.6	80.5
Soot	Soot	0.1	0.3								
Wear Metals (ppm)	D5185										
Al		5	7	7	7	8	8	8	8	9	11
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		3	3	2	3	4	6	3	5	4	4
Ca		3526	3637	3811	4050	3969	4029	4143	4240	4544	4629
Cr		<1	1	2	2	3	4	4	5	5	6
Cu		<1	10	14	17	21	24	26	36	121	311
Fe		2	39	74	100	130	172	195	252	329	476
Pb		<1	11	15	18	24	32	40	76	264	564
Mg		12	13	13	15	14	15	14	16	16	17
Mn		<1	1	2	2	2	3	3	4	5	6
Mo		1	8	12	14	17	20	20	23	25	28
Ni		<1	2	3	4	5	5	6	6	7	8
P		1291	1226	1202	1171	1188	1222	1239	1269	1303	1366
Si		5	42	50	50	51	53	50	51	52	56
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		19	16	19	23	12	22	17	24	22	22
Sn		<1	7	9	9	10	11	12	13	15	20
Zn		1861	1857	1910	1954	1970	2063	2088	2171	2220	2306
K		<5	<5	5	<5	<5	5	<5	5	5	8
Sr		<1	1	<1	2	1	<1	1	<1	1	2
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	2

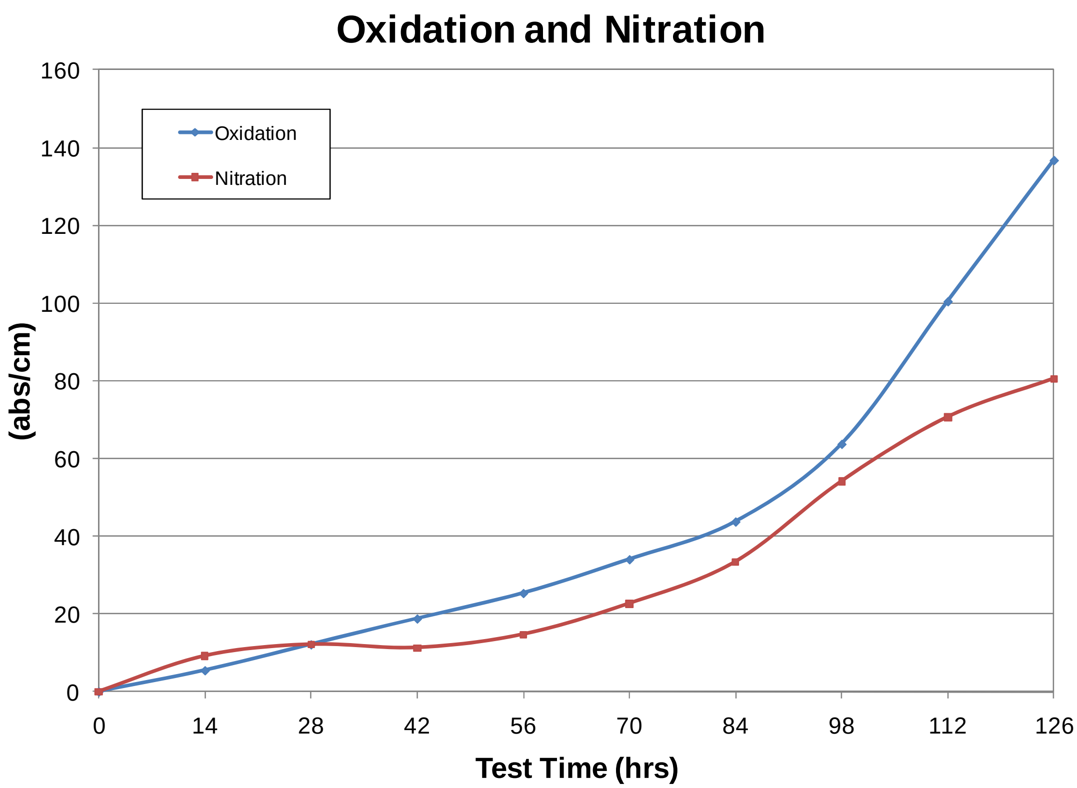
Engine Oil Analysis Trends

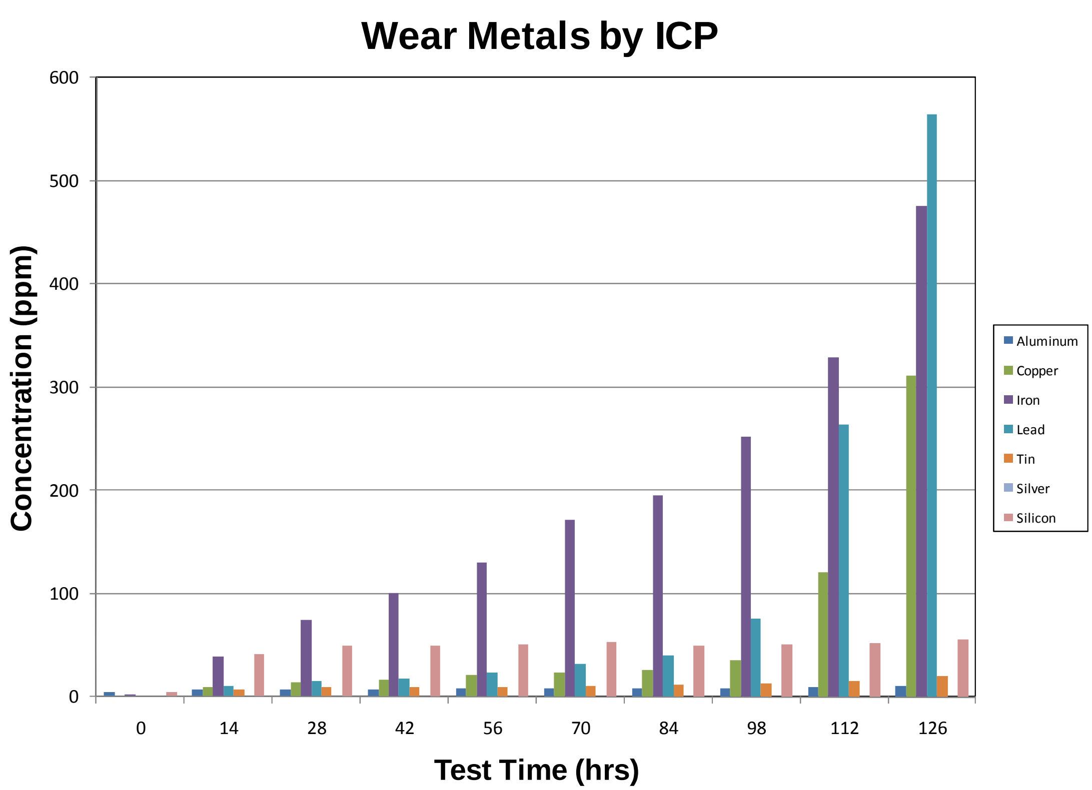





Total Acid and Base Numbers
TAN/TBN (mg KOH/g)
Total Base Number
Total Acid Number
0
1
2
3
4
5
6
7
8
9
10
11
12
0
14
28
42
56
70
84
98
112
126
Test Time (hrs)


Soot
(wt%)
0.0
0.5
1.0
1.5
2.0
2.5
0
14
28
42
56
70
84
98
112
126
Test Time (hrs)


Oxidation and Nitration
Oxidation
Nitration
(abs/cm)
160
140
120
100
80
60
40
20
0
0
14
28
42
56
70
84
98
112
126
Test Time (hrs)


Wear Metals by ICP
Concentration (ppm)
600
500
400
300
200
100
0
0
14
28
42
56
70
84
98
112
126
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

Oil Consumption Data

Average oil consumption per test hour was 0.069 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14-hr	0.87	0.24	0.63	0.63
28-hr	1.66	0.23	1.43	2.06
42-hr	1.13	0.23	0.9	2.96
56-hr	0.99	0.25	0.74	3.7
70-hr	1.4	0.24	1.16	4.86
84-hr	1.09	0.23	0.86	5.72
98-hr	1.01	0.23	0.78	6.5
112-hr	1.09	0.25	0.84	7.34
126-hr	1.6	0.25	1.35	8.69

Initial Fill	15.98	**Total Additions**	10.84
EOT Drain	16.01	**Total Samples**	2.15

(Initial Fill + Additions)	26.82
(EOT Drain + Samples)	18.16
Total Oil Consumption	8.66

Post Test Engine Ratings

Ratings	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	No	No	No	No	No	No	No	No	--
Ring No.2	No	No	No	No	No	No	No	No	--
Ring No.3	No	No	No	No	No	No	No	No	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	75.25	64.75	28.00	27.50	38.50	40.00	36.75	40.25	43.88
No.2 Groove	0.00	0.00	1.25	1.00	0.50	1.00	0.00	1.50	0.66
No.3 Groove	0.00	0.00	0.00	0.00	2.50	0.00	0.00	0.00	0.31
No.1 Land	29.25	39.50	34.00	37.50	31.25	44.25	33.25	43.00	36.50
No.2 Land	1.75	4.00	32.75	13.25	12.75	10.75	7.25	11.00	11.69
No.3 Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	2.40	2.38	2.29	4.49	3.30	3.56	4.00	2.90	3.17
No.3 Groove	1.33	1.97	2.79	2.22	3.42	2.55	2.79	3.47	2.57
No.1 Land	0.08	0.11	0.08	0.05	0.02	0.02	0.06	0.00	0.05
No.2 Land	2.43	2.39	0.68	1.46	1.55	1.72	3.03	1.85	1.89
No.3 Land	1.70	1.84	1.92	2.38	2.58	3.32	2.38	2.80	2.37
Upper Skirt	0.10	0.66	0.00	0.33	0.20	0.33	0.24	0.85	0.34
Under Crown	3.50	3.50	0.00	3.50	2.60	2.78	3.22	4.52	2.95
Front Pin Bore	1.00	1.26	1.10	1.24	1.00	1.62	1.24	1.62	1.26
Rear Pin Bore	1.00	0.77	1.10	1.24	1.00	1.62	1.24	1.62	1.20
Total, Demerits	119.79	123.13	105.96	96.16	101.17	113.52	95.45	115.38	108.82
Miscellanous									
Top Groove Fill, %	78	49	22	22	29	40	29	40	38.63
Intermediate Groove Fill, %	0	0	0	0	0	0	0	0	0.00
Top Land Heavy Carbon, %	10	24	17	20	10	27	15	24	18.38
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0	0	0.00
Valve Tulip Deposits, Merits									
Exahust	9.0	9.2	9.6	9.0	9.0	9.4	9.0	9.0	9.15
Intake	8.8	8.8	9.1	8.8	7.8	7.7	8.8	8.9	8.59

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0547	4.0554	4.0549	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0000	0.0008	0.0004	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0003	0.0007	0.0005	
Piston Skirt Diameter	4.0498	4.0499	4.0499	
Piston Skirt to Cylinder Bore Clearance	0.0048	0.0056	0.0050	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.013	0.019	0.015	
Second Ring	0.032	0.039	0.035	
Oil Control Ring	0.011	0.016	0.014	
Ring To Groove Clearance				
Second Ring	0.0020	0.0020	0.0020	0.0015"-0.003"
Oil Control Ring	0.0020	0.0020	0.0020	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2212	1.2213	1.2212	1.2207"-1.2212"
Piston Pin Clearance	0.0007	0.0008	0.0007	0.0003"-0.0012"
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2212	1.2214	1.2213	1.2207"-1.2212"
Piston Pin Clearance	0.0007	0.0009	0.0008	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0025	0.0025	0.0025	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0030	0.0022	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.006	0.004-0.010"
Rod Side Clearance	0.016	0.018	0.017	0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0550	4.0548		0.0002
	Middle	4.0548	4.0544	4.0548	0.0004
	Bottom	4.0547	4.0546		0.0001
	Taper	0.0003	0.0004		
2	Top	4.0550	4.0547		0.0003
	Middle	4.0548	4.0543	4.0547	0.0005
	Bottom	4.0545	4.0545		0.0000
	Taper	0.0005	0.0004		
3	Top	4.0552	4.0546		0.0006
	Middle	4.0550	4.0542	4.0549	0.0008
	Bottom	4.0547	4.0544		0.0003
	Taper	0.0005	0.0004		
4	Top	4.0550	4.0546		0.0004
	Middle	4.0549	4.0542	4.0548	0.0007
	Bottom	4.0546	4.0545		0.0001
	Taper	0.0004	0.0004		
5	Top	4.0552	4.0546		0.0006
	Middle	4.0549	4.0543	4.0548	0.0006
	Bottom	4.0546	4.0544		0.0002
	Taper	0.0006	0.0003		
6	Top	4.0552	4.0546		0.0006
	Middle	4.0549	4.0543	4.0547	0.0006
	Bottom	4.0545	4.0545		0.0000
	Taper	0.0007	0.0003		
7	Top	4.0557	4.0555		0.0002
	Middle	4.0555	4.0550	4.0554	0.0005
	Bottom	4.0552	4.0549		0.0003
	Taper	0.0005	0.0006		
8	Top	4.0557	4.0553		0.0004
	Middle	4.0555	4.0548	4.0554	0.0007
	Bottom	4.0552	4.0548		0.0004
	Taper	0.0005	0.0005		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0553	4.0548		0.0005
	Middle	4.0550	4.0545	4.0549	0.0005
	Bottom	4.0548	4.0546		0.0002
	Taper	0.0005	0.0003		
2	Top	4.0554	4.0548		0.0006
	Middle	4.0551	4.0543	4.0550	0.0008
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0006	0.0005		
3	Top	4.0556	4.0547		0.0009
	Middle	4.0552	4.0543	4.0550	0.0009
	Bottom	4.0547	4.0545		0.0002
	Taper	0.0009	0.0004		
4	Top	4.0554	4.0548		0.0006
	Middle	4.0551	4.5440	4.0550	0.4889
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0006	0.4895		
5	Top	4.0554	4.0546		0.0008
	Middle	4.0550	4.0543	4.0548	0.0007
	Bottom	4.0546	4.0544		0.0002
	Taper	0.0008	0.0003		
6	Top	4.0557	4.0548		0.0009
	Middle	4.0552	4.0544	4.0550	0.0008
	Bottom	4.0547	4.0545		0.0002
	Taper	0.0010	0.0004		
7	Top	4.0570	4.0558		0.0012
	Middle	4.0551	4.0552	4.0552	0.0001
	Bottom	4.0553	4.0550		0.0003
	Taper	0.0019	0.0008		
8	Top	4.0571	4.0555		0.0016
	Middle	4.0558	4.0549	4.0556	0.0009
	Bottom	4.0554	4.0549		0.0005
	Taper	0.0017	0.0006		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0003	0.0000	
	Middle	0.0002	0.0001	0.0001
	Bottom	0.0001	0.0000	
2	Top	0.0004	0.0001	
	Middle	0.0003	0.0000	0.0003
	Bottom	0.0003	0.0000	
3	Top	0.0004	0.0001	
	Middle	0.0002	0.0001	0.0001
	Bottom	0.0000	0.0001	
4	Top	0.0004	0.0002	
	Middle	0.0002	0.4898	0.0002
	Bottom	0.0002	0.0000	
5	Top	0.0002	0.0000	
	Middle	0.0001	0.0000	0.0000
	Bottom	0.0000	0.0000	
6	Top	0.0005	0.0002	
	Middle	0.0003	0.0001	0.0003
	Bottom	0.0002	0.0000	
7	Top	0.0013	0.0003	
	Middle	0.0004	0.0002	0.0002
	Bottom	0.0001	0.0001	
8	Top	0.0014	0.0002	
	Middle	0.0003	0.0001	0.0002
	Bottom	0.0002	0.0001	
Avgerage All Cylinders	Top	0.0006	0.0001	
	Middle	0.0003	0.0613	
	Bottom	0.0001	0.0000	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3431	0.3431	0.0000	0.3733	0.3744	0.0011
2	0.3431	0.3431	0.0000	0.3733	0.3746	0.0013
3	0.3431	0.3431	0.0000	0.3733	0.3752	0.0019
4	0.3431	0.3431	0.0000	0.3733	0.3746	0.0013
5	0.3431	0.3431	0.0000	0.3733	0.3740	0.0007
6	0.3431	0.3431	0.0000	0.3733	0.3740	0.0007
7	0.3431	0.3431	0.0000	0.3733	0.3744	0.0011
8	0.3431	0.3431	0.0000	0.3733	0.3741	0.0008

	Intake	Exahust
Maximum	0.0000	0.0019
Average	0.0000	0.0011

Valve Stem Measurement Changes, inches

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3412	0.3412	0.0000	0.3714	0.3714	0.0000
2	0.3412	0.3412	0.0000	0.3714	0.3714	0.0000
3	0.3412	0.3412	0.0000	0.3714	0.3714	0.0000
4	0.3412	0.3412	0.0000	0.3714	0.3714	0.0000
5	0.3412	0.3412	0.0000	0.3714	0.3714	0.0000
6	0.3412	0.3412	0.0000	0.3714	0.3714	0.0000
7	0.3412	0.3412	0.0000	0.3714	0.3714	0.0000
8	0.3412	0.3412	0.0000	0.3714	0.3714	0.0000

	Intake	Exahust
Maximum	0.0000	0.0000
Average	0.0000	0.0000

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance Intake			Stem Guide Clearance Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0019	0.0019	0.0000	0.0019	0.0030	0.0011
2	0.0019	0.0019	0.0000	0.0019	0.0032	0.0013
3	0.0019	0.0019	0.0000	0.0019	0.0038	0.0019
4	0.0019	0.0019	0.0000	0.0019	0.0032	0.0013
5	0.0019	0.0019	0.0000	0.0019	0.0026	0.0007
6	0.0019	0.0019	0.0000	0.0019	0.0026	0.0007
7	0.0019	0.0019	0.0000	0.0019	0.0030	0.0011
8	0.0019	0.0019	0.0000	0.0019	0.0027	0.0008

Maximum	0.0000	Maximum	0.0019
Average	0.0000	Average	0.0011

Valve Recession Measurement Changes, inches

	Valve Recession Intake			Valve Recession Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.029	0.047	0.018	0.026	0.066	0.040
2	0.023	0.040	0.017	0.023	0.068	0.045
3	0.025	0.040	0.015	0.026	0.084	0.058
4	0.027	0.055	0.028	0.024	0.070	0.046
5	0.024	0.050	0.026	0.027	0.068	0.041
6	0.026	0.060	0.034	0.024	0.071	0.047
7	0.025	0.051	0.026	0.026	0.064	0.038
8	0.024	0.060	0.036	0.024	0.055	0.031

Maximum	0.036	Maximum	0.058
Average	0.025	Average	0.043

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	3.49
2	3.00
3	3.80
4	2.79
5	2.24
6	2.40
7	2.78
8	3.37
9	5.34
10	2.97
11	2.39
12	4.16
13	3.04
14	2.44
15	3.10
16	2.06

Maximum	5.34
Average	3.09

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0548	4.0499	0.0049
	2	4.0547	4.0499	0.0048
	3	4.0549	4.0499	0.0050
	4	4.0548	4.0499	0.0049
	5	4.0548	4.0499	0.0049
	6	4.0547	4.0498	0.0049
	7	4.0554	4.0498	0.0056
	8	4.0554	4.0498	0.0056
Post - Test	1	4.0549	4.0496	0.0053
	2	4.0550	4.0494	0.0055
	3	4.0550	4.0493	0.0057
	4	4.0550	4.0491	0.0059
	5	4.0548	4.0493	0.0055
	6	4.0550	4.0493	0.0057
	7	4.0552	4.0494	0.0058
	8	4.0556	4.0496	0.0060

Top and Second Ring Radial Wear, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.17825	0.17790	0.00035
	2	0.17810	0.17775	0.00035
	3	0.17835	0.17795	0.00040
	4	0.17815	0.17770	0.00045
	5	0.17850	0.17795	0.00055
2	1	0.17765	0.17740	0.00025
	2	0.17805	0.17780	0.00025
	3	0.17880	0.17850	0.00030
	4	0.17865	0.17835	0.00030
	5	0.17785	0.17755	0.00030
3	1	0.17890	0.17860	0.00030
	2	0.17905	0.17870	0.00035
	3	0.17750	0.17710	0.00040
	4	0.17795	0.17755	0.00040
	5	0.17830	0.17795	0.00035
4	1	0.17795	0.17780	0.00015
	2	0.17720	0.17715	0.00005
	3	0.17810	0.17790	0.00020
	4	0.17965	0.17925	0.00040
	5	0.17860	0.17835	0.00025
5	1	0.17905	0.17870	0.00035
	2	0.17765	0.17750	0.00015
	3	0.17860	0.17825	0.00035
	4	0.17830	0.17800	0.00030
	5	0.17865	0.17845	0.00020
6	1	0.17875	0.17840	0.00035
	2	0.17870	0.17815	0.00055
	3	0.17865	0.17825	0.00040
	4	0.17800	0.17750	0.00050
	5	0.17800	0.17780	0.00020
7	1	0.17775	0.17740	0.00035
	2	0.17835	0.17810	0.00025
	3	0.17795	0.17775	0.00020
	4	0.17680	0.17650	0.00030
	5	0.17760	0.17725	0.00035
8	1	0.17880	0.17855	0.00025
	2	0.17945	0.17910	0.00035
	3	0.17790	0.17760	0.00030
	4	0.17805	0.17760	0.00045
	5	0.17815	0.17810	0.00005

Maximum	0.00055
Average	0.00031

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16210	0.16185	0.00025
	2	0.16350	0.16350	0.00000
	3	0.16180	0.16160	0.00020
	4	0.16035	0.16015	0.00020
	5	0.16160	0.16135	0.00025
2	1	0.16110	0.16090	0.00020
	2	0.16215	0.16195	0.00020
	3	0.16235	0.16205	0.00030
	4	0.16230	0.16175	0.00055
	5	0.16145	0.16110	0.00035
3	1	0.16165	0.16165	0.00000
	2	0.16305	0.16290	0.00015
	3	0.16220	0.16180	0.00040
	4	0.16045	0.16030	0.00015
	5	0.16120	0.16090	0.00030
4	1	0.16120	0.16090	0.00030
	2	0.16255	0.16250	0.00005
	3	0.16240	0.16200	0.00040
	4	0.16090	0.16070	0.00020
	5	0.16125	0.16095	0.00030
5	1	0.16020	0.16000	0.00020
	2	0.16125	0.16100	0.00025
	3	0.16100	0.16070	0.00030
	4	0.16165	0.16135	0.00030
	5	0.16065	0.15995	0.00070
6	1	0.16215	0.16150	0.00065
	2	0.16380	0.16330	0.00050
	3	0.16215	0.16155	0.00060
	4	0.16025	0.15970	0.00055
	5	0.16150	0.16095	0.00055
7	1	0.16195	0.16155	0.00040
	2	0.16275	0.16230	0.00045
	3	0.16210	0.16165	0.00045
	4	0.16235	0.16200	0.00035
	5	0.16210	0.16155	0.00055
8	1	0.16235	0.16185	0.00050
	2	0.16365	0.16335	0.00030
	3	0.16235	0.16180	0.00055
	4	0.16025	0.15960	0.00065
	5	0.16200	0.16140	0.00060

Maximum	0.00070
Average	0.00035

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.013	0.016	0.003
	2	0.039	0.036	-0.003
	3	0.013	0.014	0.001
2	1	0.014	0.017	0.003
	2	0.037	0.036	-0.001
	3	0.014	0.015	0.001
3	1	0.014	0.017	0.003
	2	0.034	0.037	0.003
	3	0.013	0.015	0.002
4	1	0.015	0.016	0.001
	2	0.032	0.035	0.003
	3	0.013	0.014	0.001
5	1	0.014	0.014	0.000
	2	0.039	0.039	0.000
	3	0.011	0.015	0.004
6	1	0.014	0.019	0.005
	2	0.032	0.038	0.006
	3	0.016	0.016	0.000
7	1	0.019	0.023	0.004
	2	0.035	0.038	0.003
	3	0.016	0.018	0.002
8	1	0.016	0.018	0.002
	2	0.035	0.039	0.004
	3	0.014	0.016	0.002

Ring No. 1 max increase	0.005
Ring No. 2 max increase	0.006
Ring No. 3 max increase	0.004

Ring No. 1 avg increase	0.003
Ring No. 2 avg increase	0.002
Ring No. 3 avg increase	0.002

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.5546	22.4868	0.0678
	2	17.0715	17.0474	0.0241
	3	14.9278	14.9118	0.0160
2	1	22.7286	22.6625	0.0661
	2	17.0190	16.9900	0.0290
	3	15.0865	15.0705	0.0160
3	1	22.5616	22.4826	0.0790
	2	17.0195	16.9853	0.0342
	3	15.0863	15.0665	0.0198
4	1	22.6288	22.5612	0.0676
	2	17.0556	17.0304	0.0252
	3	15.0773	15.0610	0.0163
5	1	22.6287	22.5547	0.0740
	2	17.1550	17.1289	0.0261
	3	15.0765	15.0583	0.0182
6	1	22.8080	22.7087	0.0993
	2	16.9982	16.9654	0.0328
	3	15.1546	15.1323	0.0223
7	1	22.4733	22.4098	0.0635
	2	17.0518	17.0262	0.0256
	3	15.0315	15.0127	0.0188
8	1	22.6932	22.6104	0.0828
	2	17.0003	16.9726	0.0277
	3	15.0126	14.9940	0.0186

Ring No. 1 max decrease	0.0993
Ring No. 2 max decrease	0.0342
Ring No. 3 max decrease	0.0223

Ring No. 1 avg decrease	0.0750
Ring No. 2 avg decrease	0.0281
Ring No. 3 avg decrease	0.0182

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.8796	27.7128	0.1668
	Bottom	27.9633	27.9035	0.0598
2	Top	27.9636	27.9347	0.0289
	Bottom	27.8521	27.8147	0.0374
3	Top	27.9308	27.8788	0.0520
	Bottom	27.9535	27.8995	0.0540
4	Top	27.7900	27.7765	0.0135
	Bottom	27.7919	27.7837	0.0082
5	Top	27.8806	27.8490	0.0316
	Bottom	27.9680	27.9068	0.0612
6	Top	27.9511	27.9173	0.0338
	Bottom	27.9531	27.9189	0.0342
7	Top	27.7803	27.7664	0.0139
	Bottom	27.7761	27.7573	0.0188
8	Top	27.8544	27.8429	0.0115
	Bottom	27.8334	27.8236	0.0098

Maximum	0.1668
Average	0.0397

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.2964	48.2793	0.0171
	Bottom	52.8102	52.7956	0.0146
2	Top	47.8993	47.8788	0.0205
	Bottom	51.7577	51.6686	0.0891
3	Top	93.7634	91.2064	2.5570
	Bottom	99.9089	96.2862	3.6227
4	Top	47.8934	47.8810	0.0124
	Bottom	51.8103	51.7718	0.0385
5	Top	69.3483	69.2706	0.0777
	Bottom	73.3443	73.2377	0.1066

Maximum	3.6227
Average	0.6556

Stanadyne Injection Pump Calibration/Evaluation

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 15241811**
Test condition : SCPL Candidate Testing	**AL:**

PUMP RPM	*Description*	*Spec.*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60-62 psi	64	64	0
	Return Fuel	225-375 cc	334	345	11
350	Low Idle	12-16 cc	14	35	21
	Housing psi.	8-12 psi	9	9	0
	Advance	3.5 deg. min	4.25	4.52	0.27
	Cold Advance Solenoid	0-1 psi.	0	0	0
750	Shut-Off	4 cc max.	0.5	0	0.5
900	Fuel Delivery	66.5 - 69.5cc	67	67	0
1600	WOT Fuel delivery	59.5 min.	64	65	1
	WOT Advance	2.5 - 3.5 deg.	2.85	2.68	0.17
	Face Cam Fuel delivery	21.5 - 23.5	22	23	1
	Face Cam Advance	5.25 - 7.25 deg.	5.93	5.63	0.3
	Low Idle	11 - 12 deg.	10.85	10.94	0.09
1825	Fuel Delivery	33 cc min.	37	47	10
1950	High Idle	15 cc max.	2	2	0
	Transfer pump psi.	125 psi max.	102	102	0
200	WOT Fuel Delivery	58 cc min.	61	62	1
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	50	54	4
	Transfer pump psi.	16 psi min.	23	27	4
	Housing psi.	0 -12 psi	7	7	0
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5	-0.5	0

*Pump calibration data to be used for reference only

Photographs

Oil Code:	LO253071	EOT Date:	09/20/10
Test No.:	LO253071-65T1-W-210	Test Length:	126

Piston Skirt Thrust - Best   Cyl 7

Piston Skirt Anti-thrust - Best   Cyl 7

Oil Code:	LO253071	EOT Date:	09/20/10
Test No.:	LO253071-65T1-W-210	Test Length:	126

Piston Skirt Thrust - Worst Cyl 2

Piston Skirt Anti-thrust - Worst Cyl 2

Oil Code:	LO253071	EOT Date:	09/20/10
Test No.:	LO253071-65T1-W-210	Test Length:	126

Piston Rings - Best Cyl 7

Piston Rings - Worst Cyl 6

Oil Code:	LO253071	EOT Date:	09/20/10
Test No.:	LO253071-65T1-W-210	Test Length:	126

Piston Undercrown - Best Cyl 7

Piston Undercrown - Worst Cyl 2

Oil Code:	LO253071	EOT Date:	09/20/10
Test No.:	LO253071-65T1-W-210	Test Length:	126

Engine Block Cylinder Bore - Best Cyl 7

Engine Block Cylinder Bore - Worst Cyl 4

Oil Code:	LO253071	EOT Date:	09/20/10
Test No.:	LO253071-65T1-W-210	Test Length:	126

Exhaustive and Intake Valve - Best Cyl 3

Oil Code:	LO253071	EOT Date:	09/20/10
Test No.:	LO253071-65T1-W-210	Test Length:	126

Exhaustive and Intake Valve - Worst Cyl 6

Oil Code:	LO253071	EOT Date:	09/20/10
Test No.:	LO253071-65T1-W-210	Test Length:	126

Rod Bearings

Oil Code:	LO253071	**EOT Date:**	09/20/10
Test No.:	LO253071-65T1-W-210	**Test Length:**	126

Main Bearings

APPENDIX C2. – EVALUATION OF LO254054 IN THE 6.5L(T) HIGH TEMPERATURE OIL ENDURANCE TEST

EVALUATION OF SCPL CANDIDATE LO-254054

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-254054
Test Fuel: Jet-A w/DCI-4A
Test Number: LO254054-65T1-W-210
Start of Test Date: July 26, 2010
End of Test Date: August 5, 2010
Test Duration: 86 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-254054 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

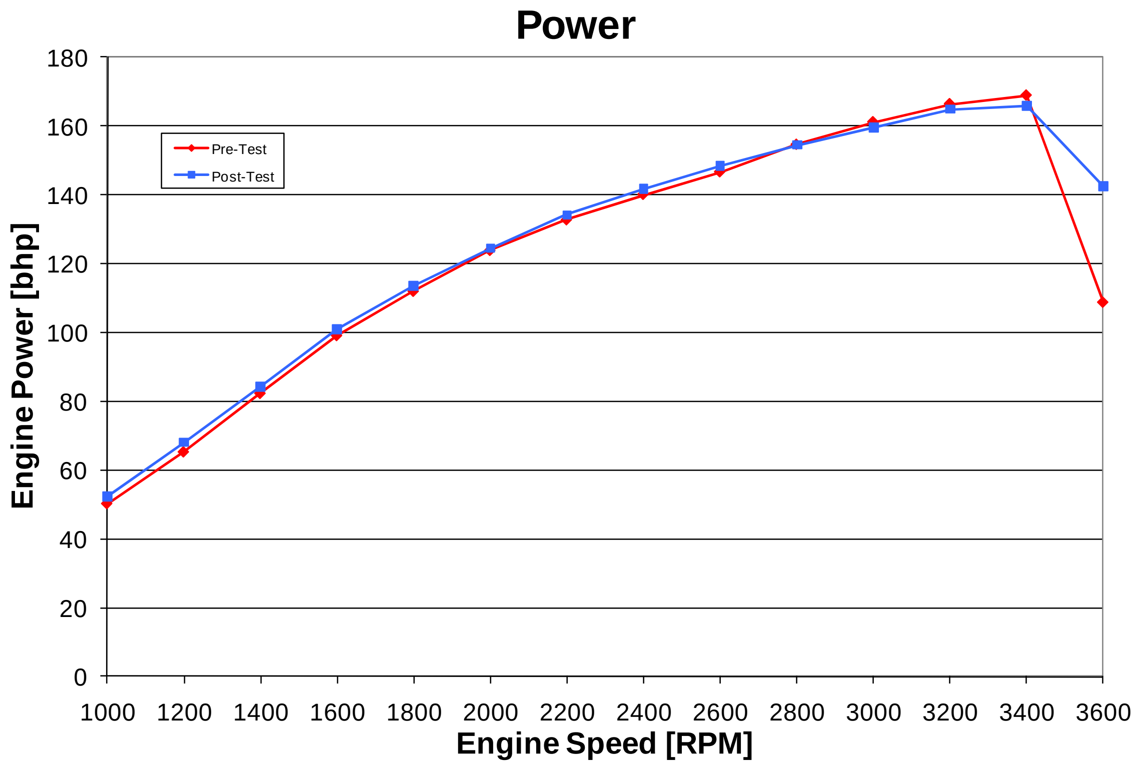
Engine Operating Conditions Summary

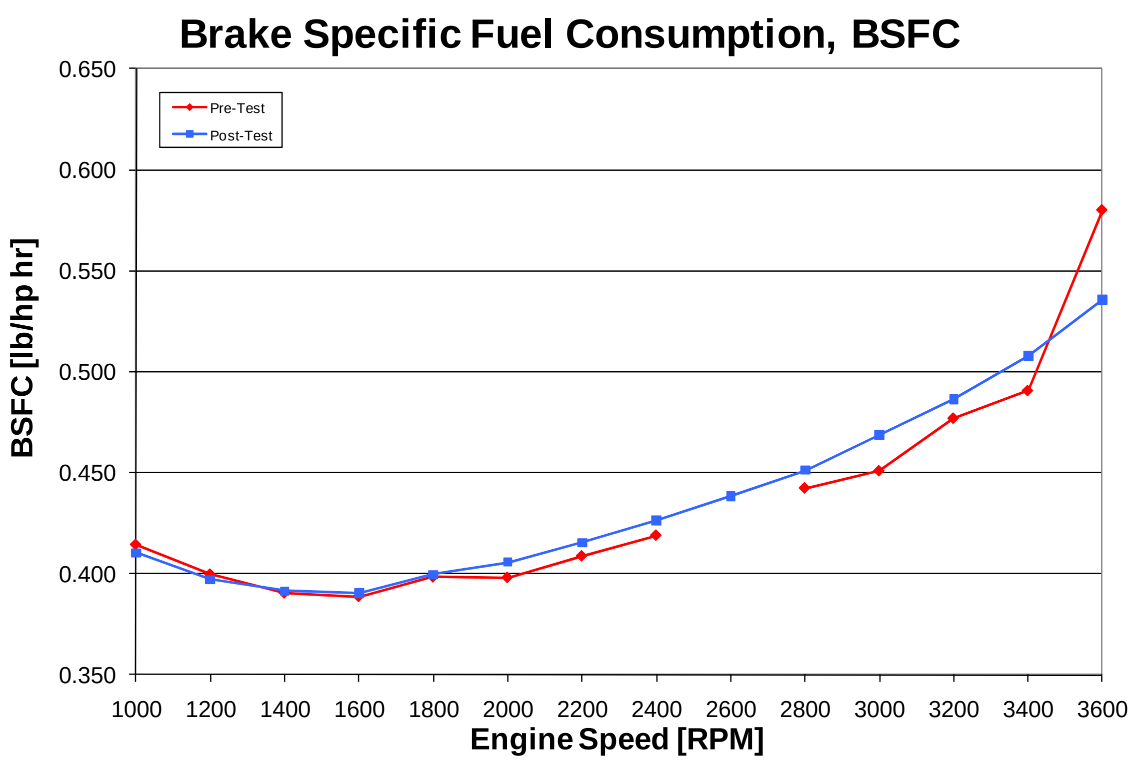
Below is a summary of the engine operating conditions over the test duration. Testing was stopped at 86hrs due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.01	1.17	900.74	1.48
Torque*	ft*lb	254.59	2.06	33.59	6.59
Fuel Flow	lb/hr	81.41	1.58	5.21	0.43
Power*	bhp	164.82	1.32	5.76	1.13
BSFC*	lb/bhp*hr	0.494	0.011	0.922	0.110
Temperatures:					
Coolant In	°F	191.33	0.57	92.90	0.61
Coolant Out	°F	205.00	0.53	100.02	0.47
Oil Sump	°F	259.96	0.91	125.44	1.44
Fuel In	°F	95.41	1.03	94.98	0.34
Intake Air	°F	69.82	2.24	63.59	2.20
Cylinder 1 Exhaust	°F	1128.23	29.43	189.51	9.13
Cylinder 2 Exhaust	°F	1113.31	20.14	178.03	9.54
Cylinder 3 Exhaust	°F	1198.94	15.99	196.75	11.81
Cylinder 4 Exhaust	°F	1122.02	23.03	184.32	10.24
Cylinder 5 Exhaust	°F	1132.85	27.40	175.94	9.74
Cylinder 6 Exhaust	°F	1158.50	29.60	179.40	9.98
Cylinder 7 Exhaust	°F	1099.28	23.83	173.35	10.75
Cylinder 8 Exhaust	°F	1163.36	24.85	182.93	11.72
Pressures:					
Oil Galley	psi	34.04	1.02	34.35	5.18
Ambient Pressure	psiA	14.29	0.04	14.28	0.04
Boost Pressure	psi	4.78	0.10	-0.14	0.06

* Non-corrected Values

Engine Performance Curves



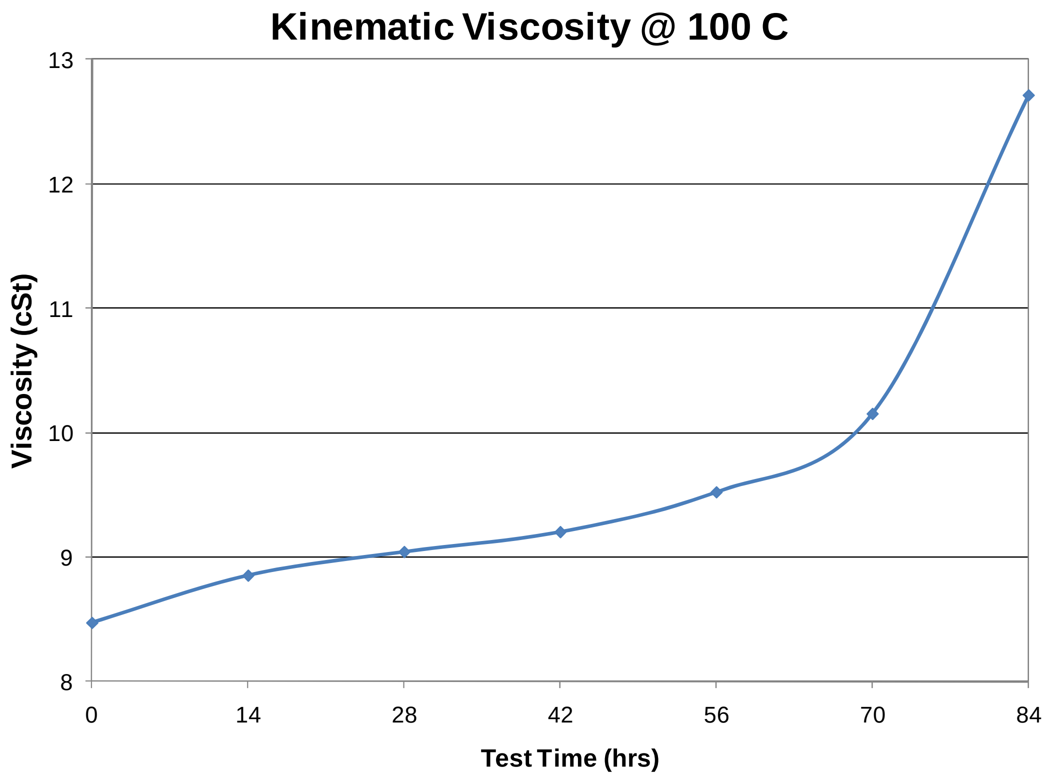


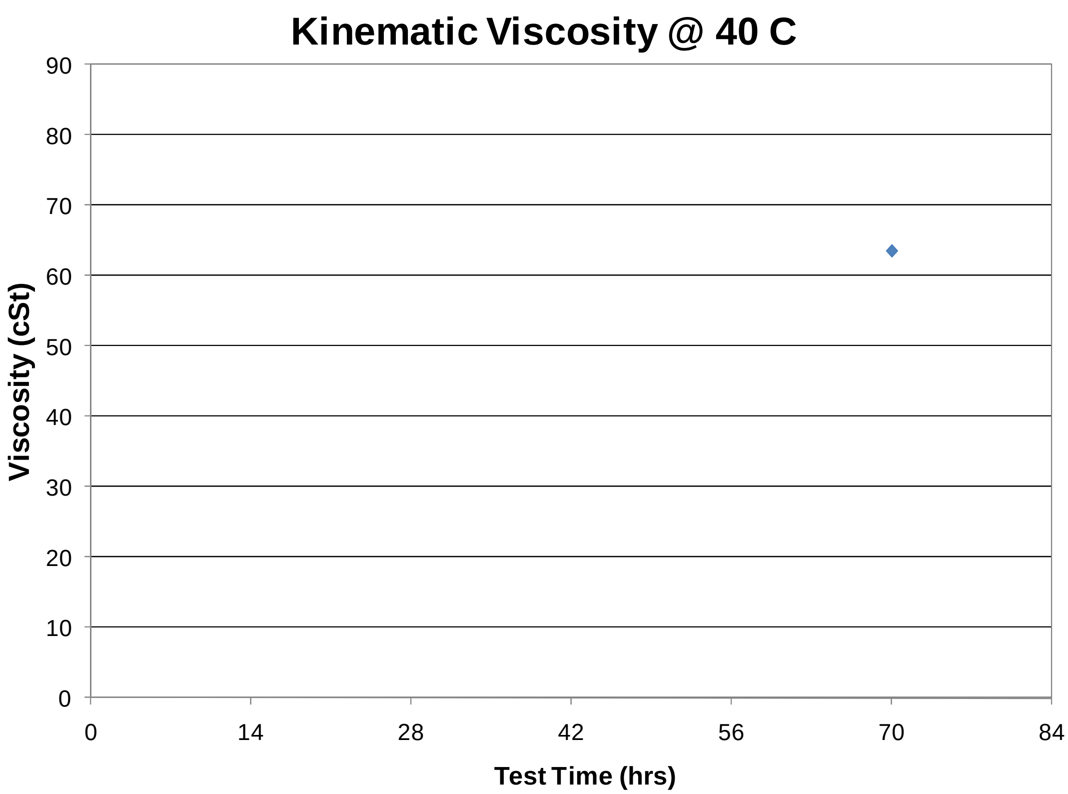
*Note – Breaks in BSFC plot due to invalid values for engine fuel flow during powercurve.

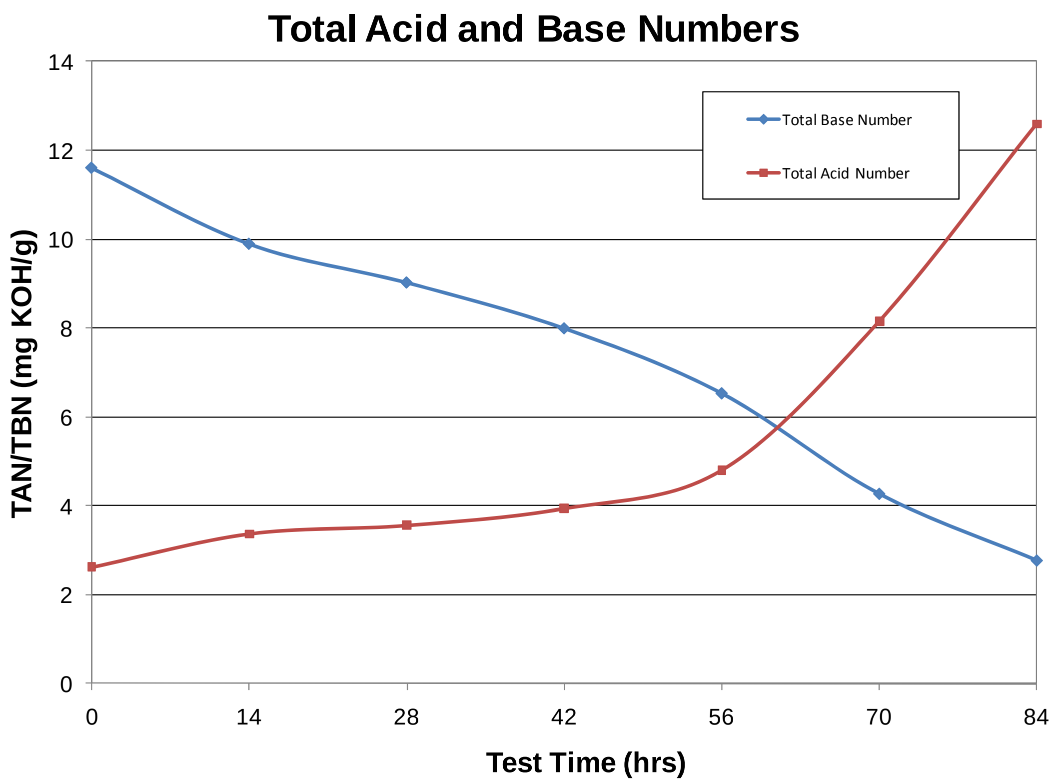
Engine Oil Analysis

Property	ASTM Test	Test Hours						
		0	14	28	42	56	70	84
Density	D4052	0.853	0.856	0.859	0.862	0.867	0.879	0.899
Viscosity @ 100°C (cSt)	D445	8.47	8.85	9.04	9.2	9.52	10.15	12.71
Viscosity @ 40°C (cSt)	D445						63.51	
Viscosity Index (dyne/cm)	D2270						146	
Total Base Number (mg KOH/g)	D4739	11.6	9.89	9.02	7.99	6.53	4.27	2.77
Total Acid Number (mg KOH/g)	D664	2.62	3.37	3.56	3.94	4.8	8.15	12.59
Oxidation (Abs./cm)	E168 FTNG	0	6.1	12.38	20.06	33.55	84.2	174.4
Nitration (Abs./cm)	E168 FTNG	0	8.6	10.81	14.97	24.95	48.43	62.2
Soot	Soot	0.068	0.269	0.433	0.561	0.765	1.065	1.633
Wear Metals (ppm)	D5185							
Al		4	6	6	6	6	7	8
Sb		<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1
B		15	13	13	16	15	16	17
Ca		3711	3863	3963	3982	4275	4344	4577
Cr		<1	<1	1	2	2	3	4
Cu		<1	8	12	13	15	71	304
Fe		2	45	80	107	141	203	369
Pb		<1	7	9	11	16	85	414
Mg		12	22	23	22	24	26	28
Mn		<1	1	2	2	2	4	5
Mo		<1	9	14	18	21	26	31
Ni		<1	1	2	3	3	4	6
P		1270	1297	1300	1317	1298	1384	1467
Si		13	45	46	49	46	52	54
Ag		<1	<1	<1	<1	<1	<1	<1
Na		20	18	16	15	15	20	21
Sn		<1	5	6	7	8	11	14
Zn		1993	2067	2113	2145	2175	2292	2426
K		<5	<5	<5	<5	<5	<5	<5
Sr		1	2	2	2	2	2	2
V		<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	3

Engine Oil Analysis Trends

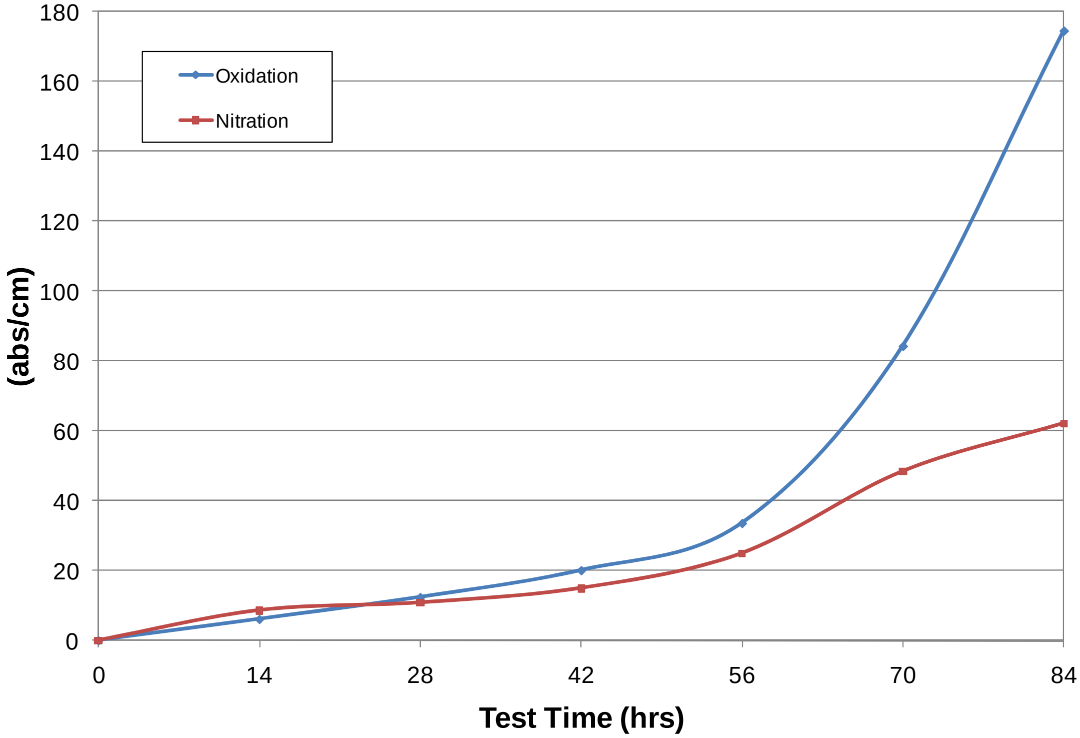




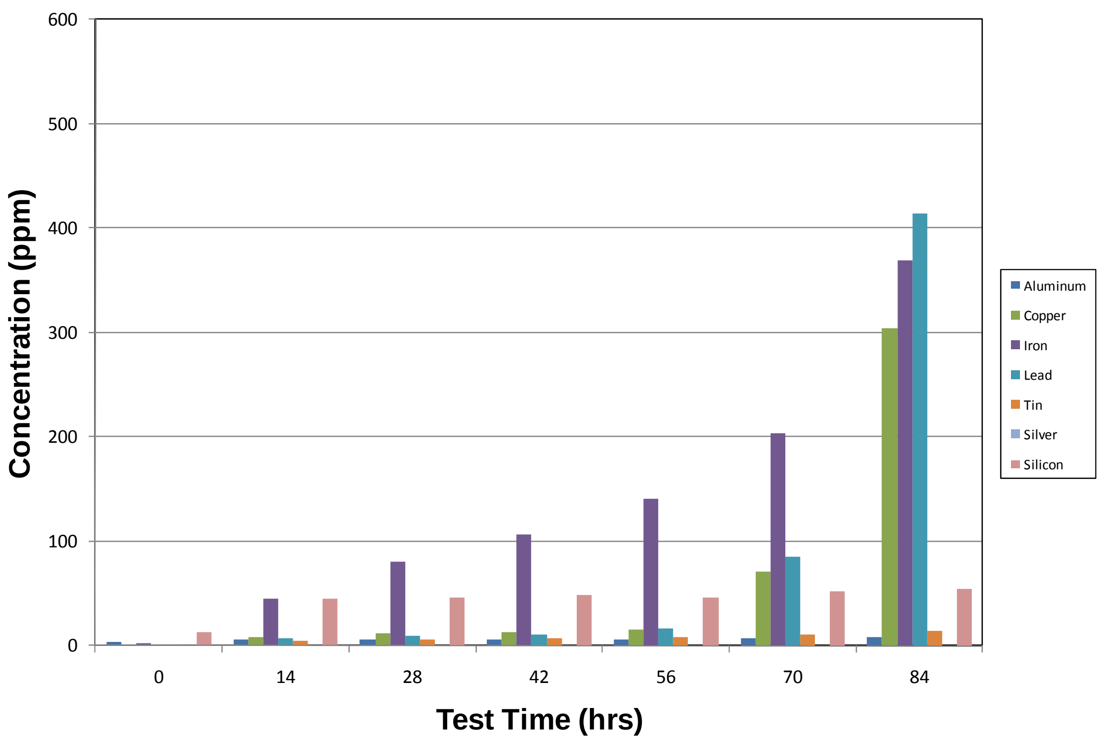

Total Acid and Base Numbers
14
12
10
8
6
4
2
0
TAN/TBN (mg KOH/g)
Total Base Number
Total Acid Number
0
14
28
42
56
70
84
Test Time (hrs)


Soot
2.5
2.0
1.5
1.0
0.5
0.0
(wt%)
0
14
28
42
56
70
84
Test Time (hrs)

Oxidation and Nitration



Wear Metals by ICP



Oil Consumption Data

Average oil consumption per test hour was 0.064 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14-hr	1.64	0.24	1.4	1.4
28-hr	1.4	0.24	1.16	2.56
42-hr	1.02	0.21	0.81	3.37
56-hr	0.76	0.25	0.51	3.88
70-hr	1.07	0.24	0.83	4.71
84-hr	2.07	0.24	1.83	6.54
	Initial Fill	14.52	**Total Additions**	7.96
	EOT Drain	15.56	**Total Samples**	1.42

(Initial Fill + Additions)	22.48
(EOT Drain + Samples)	16.98
Total Oil Consumption	5.5

Post Test Engine Ratings

Ratings	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.2	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.3	NO	NO	NO	NO	NO	NO	NO	NO	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	48.50	29.75	28.50	31.50	28.50	40.50	49.50	36.75	36.69
No.2 Groove	6.25	1.75	6.25	2.50	1.00	0.00	0.50	3.50	2.72
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	34.25	31.50	29.00	37.50	39.75	39.50	37.25	35.75	35.56
No.2 Land	10.00	7.25	13.00	6.25	12.00	7.25	10.00	54.00	14.97
No.3 Land	0.00	2.50	2.00	0.00	1.25	0.00	0.00	5.25	1.38
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	1.88	3.00	1.87	1.19	2.32	3.12	3.19	3.23	2.48
No.3 Groove	1.02	1.84	1.32	0.55	1.33	1.64	1.31	2.29	1.41
No.1 Land	0.02	0.04	0.07	0.02	0.04	0.01	0.02	0.04	0.03
No.2 Land	1.89	2.75	1.59	3.24	1.66	2.67	2.59	1.61	2.25
No.3 Land	1.97	2.04	2.02	1.46	1.47	2.81	2.10	2.16	2.00
Upper Skirt	0.20	0.47	0.20	0.20	0.20	0.31	0.20	0.50	0.29
Under Crown	3.60	2.63	2.40	2.08	2.50	2.75	3.12	5.45	3.07
Front Pin Bore	1.10	1.02	1.24	1.24	1.10	1.24	1.30	1.77	1.25
Rear Pin Bore	1.10	1.02	1.24	1.24	1.10	1.24	1.30	1.77	1.25
Total, Demerits	111.78	87.56	90.70	88.97	94.22	103.04	112.38	154.07	105.34
Miscellanous									
Top Groove Fill, %	46	20	19	24	27	29	52	40	32.13
Intermediate Groove Fill, %	2	0	2	1	0	0	0	1	0.75
Top Land Heavy Carbon, %	14	11	10	18	22	20	18	17	16.25
Top Lan Flaked Carbon, %	1	0	0	0	0	0	0	0	0.13
Valve Tulip Deposits, Merits									
Exahust	9.0	9.0	9.3	9.0	9.1	9.1	9.0	9.0	9.06
Intake	8.8	8.3	8.0	8.1	8.3	8.2	8.3	8.6	8.33

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0546	4.0554	4.0548	Cylinder 1 thru 6 ID 4.054"-4.075" Cylinder 7 thru 8 ID 4.055"-
Out of Round	0.0000	0.0009	0.0004	Maximum 0.008"
Taper	0.0003	0.0011	0.0005	
Piston Skirt Diameter	4.0495	4.0499	4.0497	
Piston Skirt to Cylinder Bore Clearance	0.0047	0.0059	0.0051	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.016	0.020	0.018	
Second Ring	0.036	0.040	0.038	
Oil Control Ring	0.013	0.020	0.017	
Ring To Groove Clearance				
Second Ring	0.0020	0.0020	0.0020	0.0015"-0.003"
Oil Control Ring	0.0020	0.0020	0.0020	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2212	1.2212	1.2212	1.2207"-1.2212"
Piston Pin Clearance	0.0007	0.0007	0.0007	0.0003"-0.0012"
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2211	1.2213	1.2212	1.2207"-1.2212"
Piston Pin Clearance	0.0006	0.0008	0.0007	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0025	0.0030	0.0029	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0030	0.0022	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.006	0.004-0.010"
Rod Side Clearance	0.015	0.020	0.017	0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0549	4.0547		0.0002
	Middle	4.0548	4.0543	4.0547	0.0005
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0004	0.0004		
2	Top	4.0550	4.0547		0.0003
	Middle	4.0548	4.0543	4.0546	0.0005
	Bottom	4.0544	4.0544		0.0000
	Taper	0.0006	0.0004		
3	Top	4.0551	4.0545		0.0006
	Middle	4.0548	4.0542	4.0546	0.0006
	Bottom	4.0544	4.0544		0.0000
	Taper	0.0007	0.0003		
4	Top	4.0550	4.0546		0.0004
	Middle	4.0548	4.0543	4.0547	0.0005
	Bottom	4.0545	4.0554		0.0009
	Taper	0.0005	0.0011		
5	Top	4.0550	4.0545		0.0005
	Middle	4.0548	4.0542	4.0547	0.0006
	Bottom	4.0545	4.0543		0.0002
	Taper	0.0005	0.0003		
6	Top	4.0551	4.0546		0.0005
	Middle	4.0549	4.0543	4.0547	0.0006
	Bottom	4.0545	4.0544		0.0001
	Taper	0.0006	0.0003		
7	Top	4.0555	4.0555		0.0000
	Middle	4.0553	4.0550	4.0552	0.0003
	Bottom	4.0551	4.0548		0.0003
	Taper	0.0004	0.0007		
8	Top	4.0557	4.0554		0.0003
	Middle	4.0555	4.0549	4.0554	0.0006
	Bottom	4.0552	4.0549		0.0003
	Taper	0.0005	0.0005		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0553	4.0546		0.0007
	Middle	4.0549	4.0541	4.0548	0.0008
	Bottom	4.0547	4.0545		0.0002
	Taper	0.0006	0.0005		
2	Top	4.0554	4.0546		0.0008
	Middle	4.0550	4.0542	4.0548	0.0008
	Bottom	4.0545	4.0545		0.0000
	Taper	0.0009	0.0004		
3	Top	4.0553	4.0545		0.0008
	Middle	4.0550	4.0541	4.0548	0.0009
	Bottom	4.0545	4.0545		0.0000
	Taper	0.0008	0.0004		
4	Top	4.0552	4.0547		0.0005
	Middle	4.0549	4.0542	4.0548	0.0007
	Bottom	4.0546	4.0545		0.0001
	Taper	0.0006	0.0005		
5	Top	4.0555	4.0544		0.0011
	Middle	4.0550	4.0541	4.0548	0.0009
	Bottom	4.0546	4.0545		0.0001
	Taper	0.0009	0.0004		
6	Top	4.0555	4.0544		0.0011
	Middle	4.0551	4.0541	4.0549	0.0010
	Bottom	4.0546	4.0545		0.0001
	Taper	0.0009	0.0004		
7	Top	4.0558	4.0555		0.0003
	Middle	4.0559	4.0551	4.0555	0.0008
	Bottom	4.0550	4.0555		0.0005
	Taper	0.0009	0.0004		
8	Top	4.0559	4.0555		0.0004
	Middle	4.0556	4.0550	4.0554	0.0006
	Bottom	4.0551	4.0552		0.0001
	Taper	0.0008	0.0005		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0004	0.0001	
	Middle	0.0001	0.0002	0.0002
	Bottom	0.0002	0.0001	
2	Top	0.0004	0.0001	
	Middle	0.0002	0.0001	0.0001
	Bottom	0.0001	0.0001	
3	Top	0.0002	0.0000	
	Middle	0.0002	0.0001	0.0001
	Bottom	0.0001	0.0001	
4	Top	0.0002	0.0001	
	Middle	0.0001	0.0001	0.0001
	Bottom	0.0001	0.0009	
5	Top	0.0005	0.0001	
	Middle	0.0002	0.0001	0.0001
	Bottom	0.0001	0.0002	
6	Top	0.0004	0.0002	
	Middle	0.0002	0.0002	0.0002
	Bottom	0.0001	0.0001	
7	Top	0.0003	0.0000	
	Middle	0.0006	0.0001	0.0004
	Bottom	0.0001	0.0007	
8	Top	0.0002	0.0001	
	Middle	0.0001	0.0001	0.0001
	Bottom	0.0001	0.0003	
Avgerage All Cylinders	Top	0.0003	0.0001	
	Middle	0.0002	0.0001	
	Bottom	0.0001	0.0003	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3431	0.3432	0.0001	0.3736	0.3742	0.0006
2	0.3431	0.3432	0.0001	0.3736	0.3748	0.0012
3	0.3431	0.3433	0.0002	0.3736	0.3742	0.0006
4	0.3431	0.3432	0.0001	0.3736	0.3742	0.0006
5	0.3431	0.3432	0.0001	0.3736	0.3750	0.0014
6	0.3431	0.3432	0.0001	0.3735	0.3742	0.0007
7	0.3431	0.3432	0.0001	0.3736	0.3742	0.0006
8	0.3431	0.3432	0.0001	0.3736	0.3742	0.0006

Maximum	0.0002	Maximum	0.0014
Average	0.0001	Average	0.0008

Valve Stem Measurement Changes, inches

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3410	0.3410	0.0000	0.3711	0.3709	0.0002
2	0.3410	0.3412	-0.0002	0.3712	0.3711	0.0001
3	0.3410	0.3411	-0.0001	0.3712	0.3711	0.0001
4	0.3410	0.3409	0.0001	0.3711	0.3710	0.0001
5	0.3411	0.3412	-0.0001	0.3712	0.3708	0.0004
6	0.3410	0.3412	-0.0002	0.3712	0.3710	0.0002
7	0.3410	0.3411	-0.0001	0.3712	0.3710	0.0002
8	0.3410	0.3411	-0.0001	0.3712	0.3708	0.0004

Maximum	0.0001	Maximum	0.0004
Average	-0.0001	Average	0.0002

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance Intake			Stem Guide Clearance Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0021	0.0022	0.0001	0.0025	0.0033	0.0008
2	0.0021	0.0020	-0.0001	0.0024	0.0037	0.0013
3	0.0021	0.0022	0.0001	0.0024	0.0031	0.0007
4	0.0021	0.0023	0.0002	0.0025	0.0032	0.0007
5	0.0020	0.0020	0.0000	0.0024	0.0042	0.0018
6	0.0021	0.0020	-0.0001	0.0023	0.0032	0.0009
7	0.0021	0.0021	0.0000	0.0024	0.0032	0.0008
8	0.0021	0.0021	0.0000	0.0024	0.0034	0.0010

Maximum	0.0002
Average	0.0000

Maximum	0.0018
Average	0.0010

Valve Recession Measurement Changes, inches

	Valve Recession Intake			Valve Recession Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.026	0.048	0.022	0.024	0.056	0.032
2	0.027	0.042	0.015	0.026	0.054	0.028
3	0.026	0.039	0.013	0.023	0.060	0.037
4	0.023	0.042	0.019	0.025	0.054	0.029
5	0.023	0.070	0.047	0.025	0.058	0.033
6	0.023	0.042	0.019	0.022	0.054	0.032
7	0.024	0.047	0.023	0.028	0.055	0.027
8	0.024	0.045	0.021	0.024	0.056	0.032

Maximum	0.047
Average	0.022

Maximum	0.037
Average	0.031

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	2.32
2	1.23
3	1.55
4	2.91
5	1.20
6	1.15
7	1.59
8	1.79
9	1.45
10	1.35
11	1.22
12	1.45
13	1.09
14	1.66
15	1.27
16	1.56

Maximum	2.91
Average	1.55

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0547	4.0499	0.0048
	2	4.0546	4.0499	0.0047
	3	4.0546	4.0496	0.0050
	4	4.0547	4.0496	0.0051
	5	4.0547	4.0498	0.0049
	6	4.0547	4.0497	0.0050
	7	4.0552	4.0497	0.0055
	8	4.0554	4.0495	0.0059
Post - Test	1	4.0548	4.0493	0.0055
	2	4.0548	4.0493	0.0055
	3	4.0548	4.0488	0.0060
	4	4.0548	4.0488	0.0060
	5	4.0548	4.0490	0.0058
	6	4.0549	4.0489	0.0060
	7	4.0555	4.0490	0.0065
	8	4.0554	4.0490	0.0064

Top and Second Ring Radial Wear, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.17915	0.17880	0.00035
	2	0.17740	0.17730	0.00010
	3	0.17970	0.17920	0.00050
	4	0.18000	0.17945	0.00055
	5	0.17945	0.17940	0.00005
2	1	0.17985	0.17955	0.00030
	2	0.18015	0.17980	0.00035
	3	0.18065	0.18025	0.00040
	4	0.18045	0.18025	0.00020
	5	0.17910	0.17880	0.00030
3	1	0.18050	0.18030	0.00020
	2	0.18050	0.18000	0.00050
	3	0.17855	0.17820	0.00035
	4	0.17890	0.17860	0.00030
	5	0.18020	0.18005	0.00015
4	1	0.17890	0.17860	0.00030
	2	0.17930	0.17895	0.00035
	3	0.17945	0.17905	0.00040
	4	0.17880	0.17835	0.00045
	5	0.17860	0.17825	0.00035
5	1	0.17930	0.17890	0.00040
	2	0.17970	0.17935	0.00035
	3	0.18060	0.18025	0.00035
	4	0.17920	0.17880	0.00040
	5	0.17870	0.17840	0.00030
6	1	0.17985	0.17935	0.00050
	2	0.17975	0.17940	0.00035
	3	0.18095	0.18055	0.00040
	4	0.18090	0.18070	0.00020
	5	0.18055	0.18030	0.00025
7	1	0.17870	0.17830	0.00040
	2	0.17835	0.17800	0.00035
	3	0.17800	0.17765	0.00035
	4	0.18005	0.17965	0.00040
	5	0.17990	0.17970	0.00020
8	1	0.17905	0.17860	0.00045
	2	0.17930	0.17885	0.00045
	3	0.17835	0.17785	0.00050
	4	0.17815	0.17770	0.00045
	5	0.17870	0.17835	0.00035

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16145	0.16105	0.00040
	2	0.16130	0.16100	0.00030
	3	0.16220	0.16165	0.00055
	4	0.16260	0.16200	0.00060
	5	0.16160	0.16125	0.00035
2	1	0.16150	0.16140	0.00010
	2	0.16095	0.16080	0.00015
	3	0.16145	0.16090	0.00055
	4	0.16230	0.16195	0.00035
	5	0.16165	0.16150	0.00015
3	1	0.16140	0.16100	0.00040
	2	0.16220	0.16170	0.00050
	3	0.16145	0.16100	0.00045
	4	0.16055	0.16020	0.00035
	5	0.16090	0.16070	0.00020
4	1	0.16110	0.16045	0.00065
	2	0.15950	0.15895	0.00055
	3	0.16160	0.16090	0.00070
	4	0.16345	0.16285	0.00060
	5	0.16180	0.16110	0.00070
5	1	0.16150	0.16095	0.00055
	2	0.16225	0.16165	0.00060
	3	0.16120	0.16055	0.00065
	4	0.15995	0.15920	0.00075
	5	0.16100	0.16035	0.00065
6	1	0.16160	0.16105	0.00055
	2	0.16135	0.16075	0.00060
	3	0.16165	0.16125	0.00040
	4	0.16230	0.16145	0.00085
	5	0.16165	0.16105	0.00060
7	1	0.16110	0.16045	0.00065
	2	0.15985	0.15920	0.00065
	3	0.16155	0.16090	0.00065
	4	0.16335	0.16265	0.00070
	5	0.16195	0.16125	0.00070
8	1	0.16125	0.16075	0.00050
	2	0.16095	0.16060	0.00035
	3	0.16205	0.16125	0.00080
	4	0.16260	0.16195	0.00065
	5	0.16185	0.16140	0.00045

Maximum	0.00055
Average	0.00035

Maximum	0.00085
Average	0.00052

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.017	0.016	-0.001
	2	0.037	0.037	0.000
	3	0.017	0.017	0.000
2	1	0.016	0.016	0.000
	2	0.036	0.041	0.005
	3	0.018	0.017	-0.001
3	1	0.016	0.016	0.000
	2	0.037	0.037	0.000
	3	0.013	0.015	0.002
4	1	0.016	0.016	0.000
	2	0.037	0.040	0.003
	3	0.018	0.017	-0.001
5	1	0.018	0.021	0.003
	2	0.037	0.037	0.000
	3	0.018	0.017	-0.001
6	1	0.018	0.017	-0.001
	2	0.037	0.038	0.001
	3	0.018	0.017	-0.001
7	1	0.020	0.019	-0.001
	2	0.040	0.043	0.003
	3	0.020	0.020	0.000
8	1	0.020	0.019	-0.001
	2	0.039	0.041	0.002
	3	0.016	0.024	0.008

Ring No. 1 max increase	0.003
Ring No. 2 max increase	0.005
Ring No. 3 max increase	0.008

Ring No. 1 avg increase	0.000
Ring No. 2 avg increase	0.002
Ring No. 3 avg increase	0.001

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.9511	22.8944	0.0567
	2	16.9005	16.8814	0.0191
	3	15.1702	15.1563	0.0139
2	1	22.8653	22.8048	0.0605
	2	16.9110	16.8870	0.0240
	3	15.0373	15.0234	0.0139
3	1	22.7925	22.7355	0.0570
	2	16.9583	16.9340	0.0243
	3	15.1730	15.1578	0.0152
4	1	22.9240	22.8660	0.0580
	2	16.9680	16.9420	0.0260
	3	15.1792	15.1601	0.0191
5	1	23.0168	22.9570	0.0598
	2	16.9448	16.9240	0.0208
	3	15.1096	15.0967	0.0129
6	1	22.9989	22.9356	0.0633
	2	16.9330	16.9106	0.0224
	3	15.0073	14.9910	0.0163
7	1	22.8118	22.7538	0.0580
	2	16.8884	16.8691	0.0193
	3	15.1570	15.1433	0.0137
8	1	22.8296	22.7576	0.0720
	2	16.9704	16.9535	0.0169
	3	15.0962	15.0795	0.0167

Ring No. 1 max decrease	0.0720
Ring No. 2 max decrease	0.0260
Ring No. 3 max decrease	0.0191

Ring No. 1 avg decrease	0.0607
Ring No. 2 avg decrease	0.0216
Ring No. 3 avg decrease	0.0152

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.8253	27.8142	0.0111
	Bottom	27.7828	27.7583	0.0245
2	Top	27.7075	27.6827	0.0248
	Bottom	27.7367	27.7305	0.0062
3	Top	27.8030	27.7913	0.0117
	Bottom	27.8555	27.8499	0.0056
4	Top	27.7907	27.7769	0.0138
	Bottom	27.8094	27.7775	0.0319
5	Top	27.7712	27.7354	0.0358
	Bottom	27.6999	27.6659	0.0340
6	Top	27.7131	27.6915	0.0216
	Bottom	27.6810	27.6586	0.0224
7	Top	27.8322	27.8035	0.0287
	Bottom	27.6848	27.6674	0.0174
8	Top	27.7043	27.6920	0.0123
	Bottom	27.6962	27.6747	0.0215

Maximum	0.0358
Average	0.0202

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.3539	48.3394	0.0145
	Bottom	52.6746	52.6612	0.0134
2	Top	48.3971	48.3822	0.0149
	Bottom	52.4269	52.3687	0.0582
3	Top	93.8999	91.6031	2.2968
	Bottom	99.8241	97.1836	2.6405
4	Top	48.5134	48.4951	0.0183
	Bottom	52.4008	52.3751	0.0257
5	Top	69.3515	69.2962	0.0553
	Bottom	73.2134	73.1528	0.0606

Maximum	2.6405
Average	0.5198

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 15240441**
Test condition : SCPL Candidate Testing	**AL:**

PUMP RPM	*Description*	*Spec.*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60-62 psi	62	65	3
	Return Fuel	225-375 cc	344	370	26
350	Low Idle	12-16 cc	13	54	41
	Housing psi.	8-12 psi	8	8.5	0.5
	Advance	3.5 deg. min	5.36	2.1	3.26
	Cold Advance Solenoid	0-1 psi.	0	0	0
750	Shut-Off	4 cc max.	0.5	0	0.5
900	Fuel Delivery	66.5 - 69.5cc	67	69	2
1600	WOT Fuel delivery	59.5 min.	62	65	3
	WOT Advance	2.5 - 3.5 deg.	3.34	3.3	0.04
	Face Cam Fuel delivery	21.5 - 23.5	22	22	0
	Face Cam Advance	5.25 - 7.25 deg.	7.11	7.7	0.59
	Low Idle	11 - 12 deg.	11.07	10.41	0.66
1825	Fuel Delivery	33 cc min.	35	44	9
1950	High Idle	15 cc max.	3	2	1
	Transfer pump psi.	125 psi max.	102	104	2
200	WOT Fuel Delivery	58 cc min.	61	63	2
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	51	52	1
	Transfer pump psi.	16 psi min.	22	27	5
	Housing psi.	0 -12 psi	2	6	4
	Air Timing	-.5 deg.(+/-.5 deg)		-0.5	0.5
	Fluid Temp. Deg. C				
	Date		7/7/2010	8/30/2010	

*Pump calibration data to be used for reference only

Photographs

Oil Code:	LO-254054	EOT Date:	08/05/10
Test No.:	LO254054-65T1-W-210	Test Length:	86

Piston Skirt Thrust - Best Cyl 2

Piston Skirt Anti-thrust - Best Cyl 2

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-254054	EOT Date:	08/05/10
Test No.:	LO254054-65T1-W-210	Test Length:	86

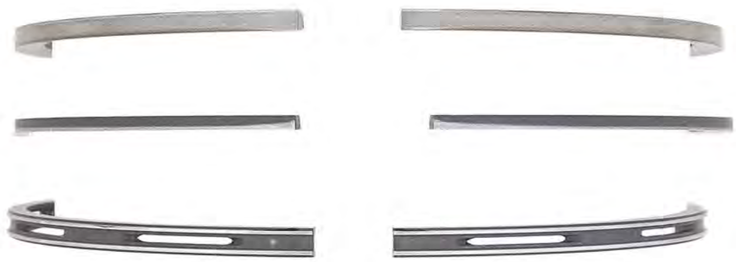
Piston Skirt Thrust - Worst Cyl 8

Piston Skirt Anti-thrust - Worst Cyl 8

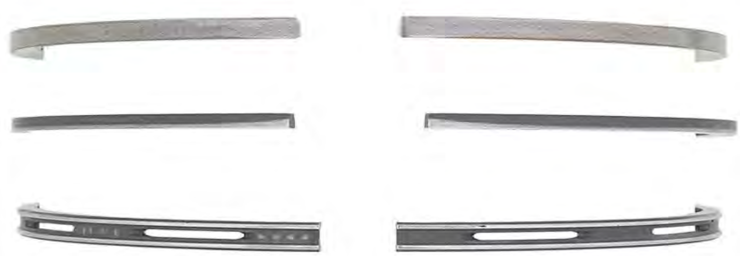
GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-254054	EOT Date:	08/05/10
Test No.:	LO254054-65T1-W-210	Test Length:	86

Piston Rings - Best Cyl 1



Piston Rings - Worst Cyl 8

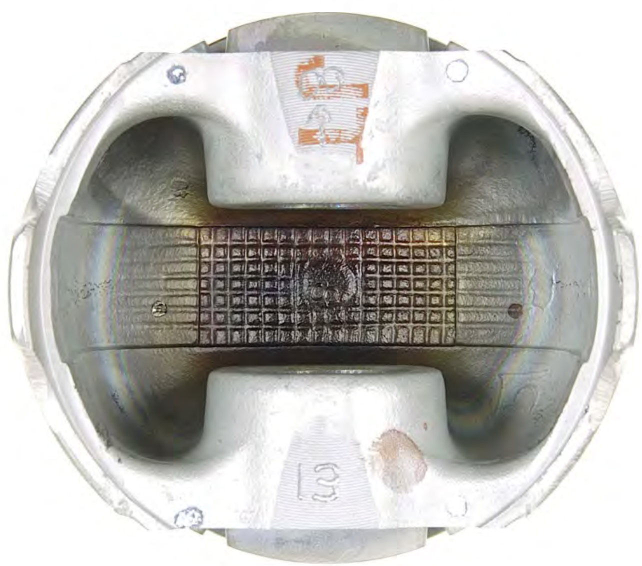


GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-254054	EOT Date:	08/05/10
Test No.:	LO254054-65T1-W-210	Test Length:	86

Piston Undercrown - Best Cyl 2

Piston Undercrown - Worst Cyl 8



Oil Code:	LO-254054	**EOT Date:**	08/05/10
Test No.:	LO254054-65T1-W-210	**Test Length:**	86

Engine Block Cylinder Bore - Best Cyl 1

Engine Block Cylinder Bore - Worst Cyl 8

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-254054	**EOT Date:**	08/05/10
Test No.:	LO254054-65T1-W-210	**Test Length:**	86

Exhaust and Intake Valve - Best Cyl 1

Oil Code:	LO-254054	**EOT Date:**	08/05/10
Test No.:	LO254054-65T1-W-210	**Test Length:**	86

Exhaust and Intake Valve - Worst Cyl 4

Oil Code:	LO-254054	EOT Date:	08/05/10
Test No.:	LO254054-65T1-W-210	Test Length:	86

Rod Bearings

Oil Code:	LO-254054	**EOT Date:**	08/05/10
Test No.:	LO254054-65T1-W-210	**Test Length:**	86

Main Bearings

APPENDIX C3. – EVALUATION OF LO25033 IN THE 6.5L(T) HIGH TEMPERATURE OIL ENDURANCE TEST

EVALUATION OF SCPL CANDIDATE LO-250033

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-250033
Test Fuel: Jet-A w/DCI-4A
Test Number: LO250033-65T1-W-210
Start of Test Date: October 20, 2010
End of Test Date: November 11, 2010
Test Duration: 168 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-250033 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

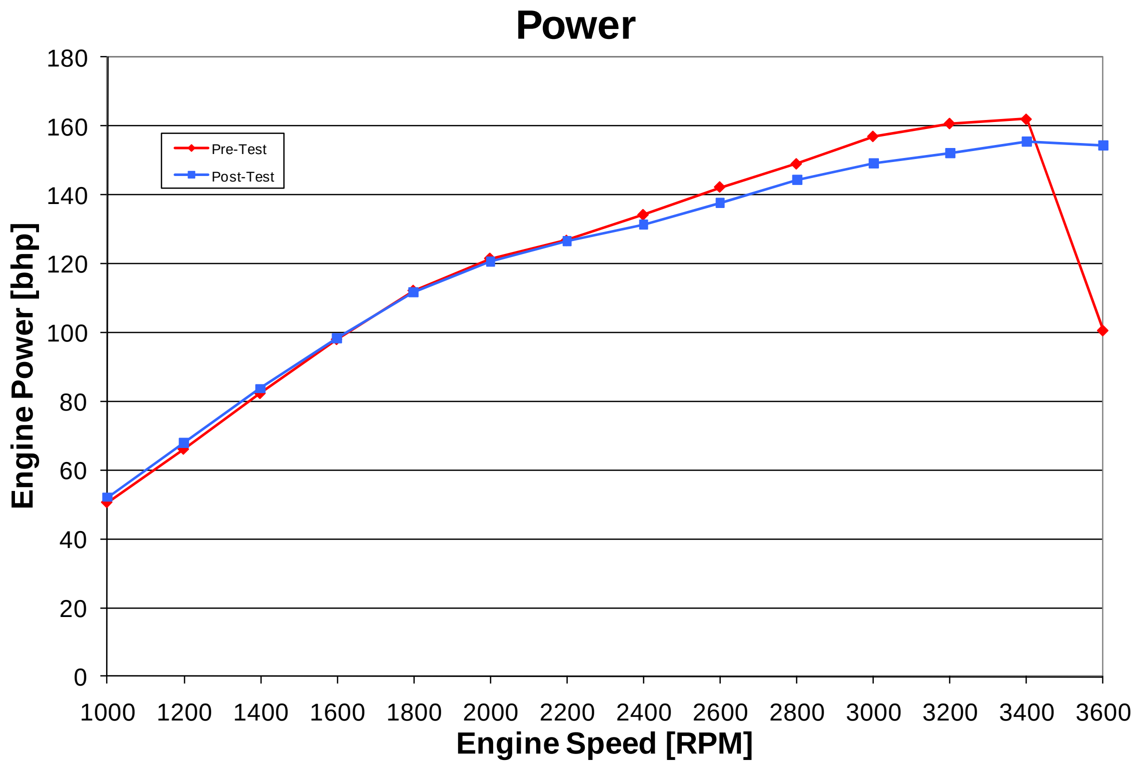
Engine Operating Conditions Summary

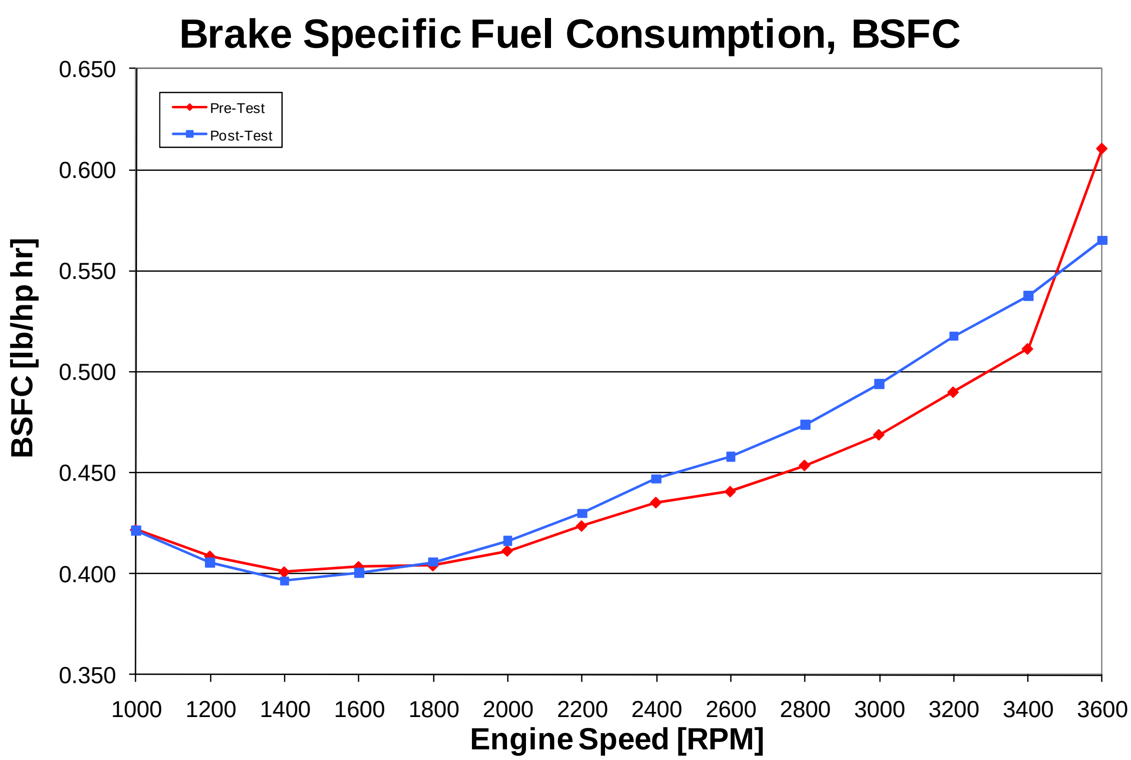
Below is a summary of the engine operating conditions over the test duration. Testing was stopped at 168hrs due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.01	0.75	900.30	2.20
Torque*	ft*lb	253.87	2.99	44.28	23.15
Fuel Flow	lb/hr	82.82	1.29	6.00	1.23
Power*	bhp	164.36	1.93	7.59	3.98
BSFC*	lb/bhp*hr	0.504	0.011	0.891	0.215
Temperatures:					
Coolant In	°F	190.84	0.75	92.28	1.06
Coolant Out	°F	205.00	0.70	100.00	0.70
Oil Sump	°F	260.04	0.37	125.67	1.86
Fuel In	°F	95.09	0.50	94.99	0.34
Intake Air	°F	64.19	3.89	61.41	2.47
Cylinder 1 Exhaust	°F	1095.59	31.46	171.26	41.09
Cylinder 2 Exhaust	°F	1082.53	18.05	182.37	24.28
Cylinder 3 Exhaust	°F	1123.25	50.99	182.47	51.87
Cylinder 4 Exhaust	°F	1136.45	14.02	203.21	28.85
Cylinder 5 Exhaust	°F	1168.95	26.40	204.68	35.10
Cylinder 6 Exhaust	°F	1197.56	14.82	194.89	29.45
Cylinder 7 Exhaust	°F	1149.01	25.70	196.48	33.71
Cylinder 8 Exhaust	°F	1170.32	15.13	192.72	30.07
Pressures:					
Oil Galley	psi	41.50	1.25	42.81	5.22
Ambient Pressure	psiA	14.31	0.11	14.30	0.10
Boost Pressure	psi	5.31	0.21	-0.13	0.07

* Non-corrected Values

Engine Performance Curves

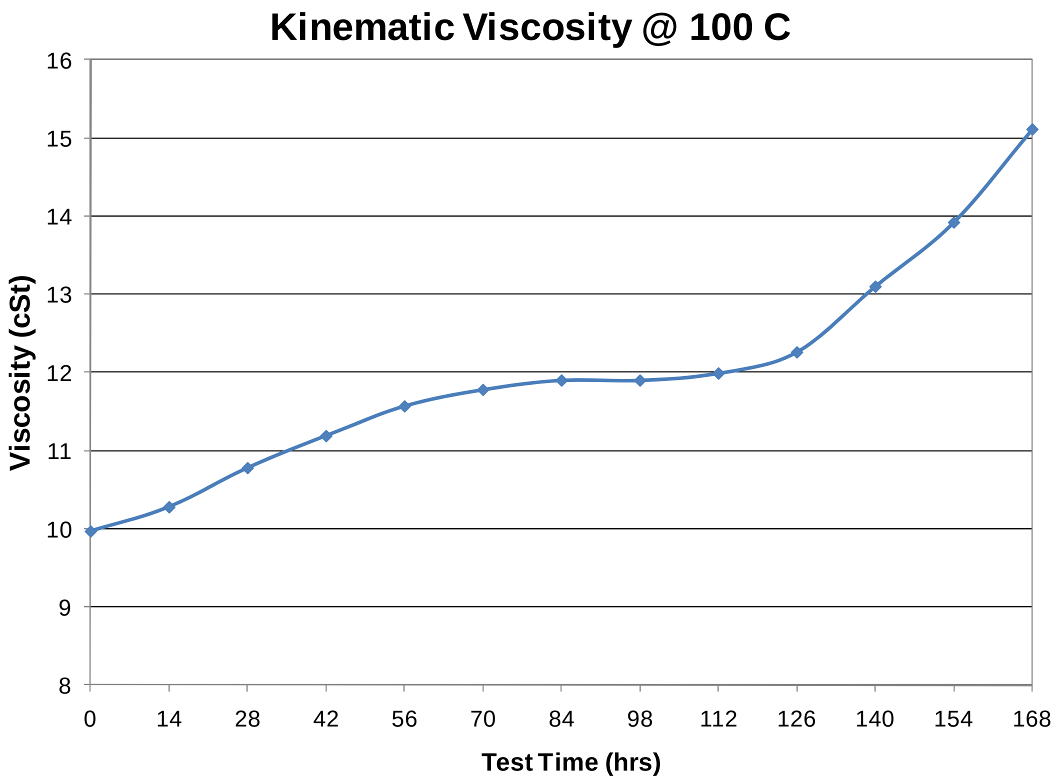


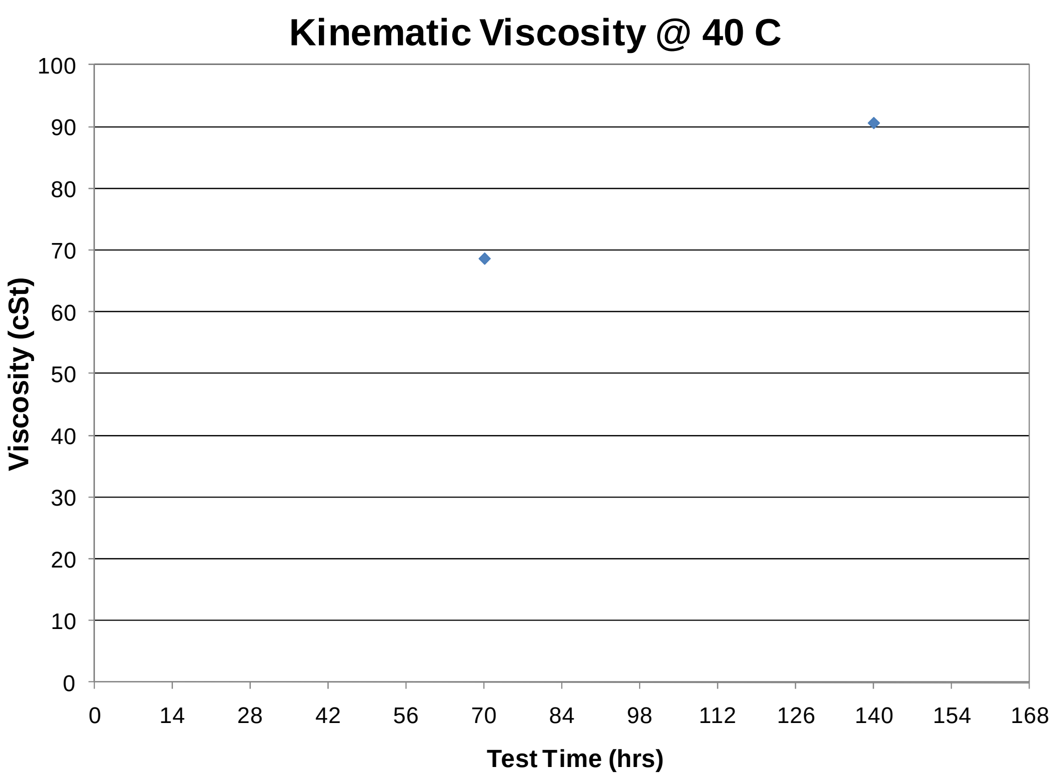


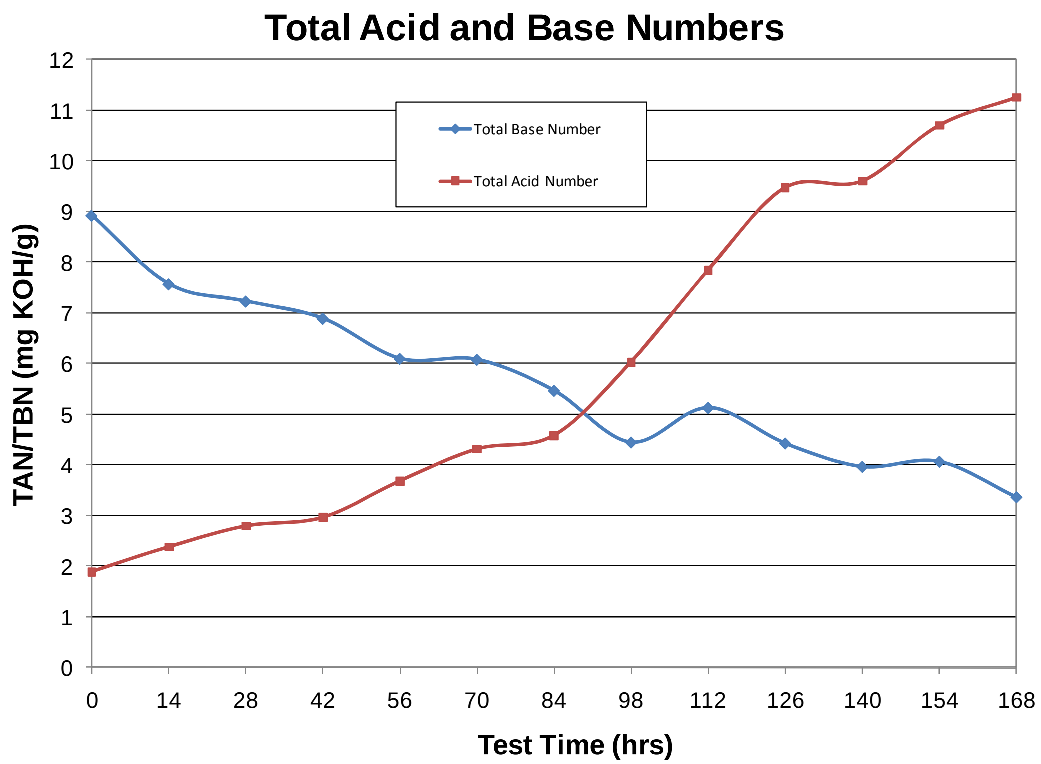
Engine Oil Analysis

Property	ASTM Test	Test Hours												
		0	14	28	42	56	70	84	98	112	126	140	154	168
Density	D4052	0.845	0.8484	0.8514	0.8545	0.8578	0.8611	0.8651	0.8689	0.8793	0.881	0.888	0.8922	0.8976
Viscosity @ 100°C (cSt)	D445	10.0	10.3	10.8	11.2	11.6	11.8	11.9	11.9	12.0	12.3	13.1	13.9	15.1
Viscosity @ 40°C (cSt)	D445						68.66					90.6		
Viscosity Index (dyne/cm)	D2270						169.0					144.0		
Total Base Number (mg KOH/g)	D4739	8.9	7.6	7.2	6.9	6.1	6.1	5.5	4.5	5.1	4.4	4.0	4.1	3.4
Total Acid Number (mg KOH/g)	D664	1.9	2.4	2.8	3.0	3.7	4.3	4.6	6.0	7.8	9.5	9.6	10.7	11.3
Oxidation (Abs./cm)	E168 FTNG	0.0	5.2	10.8	16.5	23.2	30.2	38.4	47.9	61.1	83.0	105.1	118.3	133.9
Nitration (Abs./cm)	E168 FTNG	0.0	6.0	7.0	10.5	16.9	24.5	34.6	42.7	51.2	62.2	68.5	70.5	74.7
Soot	Soot	0.1	0.5	0.6	0.8	1.1	1.2	1.4	1.7	2.0	2.3	2.5	2.7	3.2
Wear Metals (ppm)	D5185													
Al		1	2	3	3	3	3	4	4	4	5	4	5	4
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		66	52	56	57	56	57	58	60	63	63	65	67	68
Ca		769	872	926	913	985	1015	1075	1135	1152	1207	1278	1291	1286
Cr		<1	1	2	3	3	4	4	4	5	6	6	6	7
Cu		<1	42	44	45	48	48	48	50	51	55	59	64	68
Fe		2	53	82	123	197	300	395	528	599	722	831	849	902
Pb		<1	12	14	15	17	22	28	35	47	72	123	167	232
Mg		1099	1211	1262	1273	1334	1394	1464	1623	1559	1633	1657	1750	1717
Mn		<1	1	2	2	3	3	4	4	5	6	6	7	7
Mo		44	54	62	68	68	77	79	83	86	90	96	95	98
Ni		<1	3	4	5	5	6	7	7	8	8	9	8	9
P		1116	1102	1090	1103	1179	1176	1211	1286	1317	1379	1441	1443	1484
Si		6	48	60	66	69	72	72	71	70	70	67	66	63
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		8	8	6	8	5	9	11	10	15	16	13	15	12
Sn		<1	9	10	11	11	13	13	13	14	15	13	12	13
Zn		1278	1321	1377	1439	1526	1553	1618	1687	1755	1841	1896	1924	1940
K		<5	<5	<5	<5	<5	<5	<5	5	<5	<5	8	5	5
Sr		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Engine Oil Analysis Trends

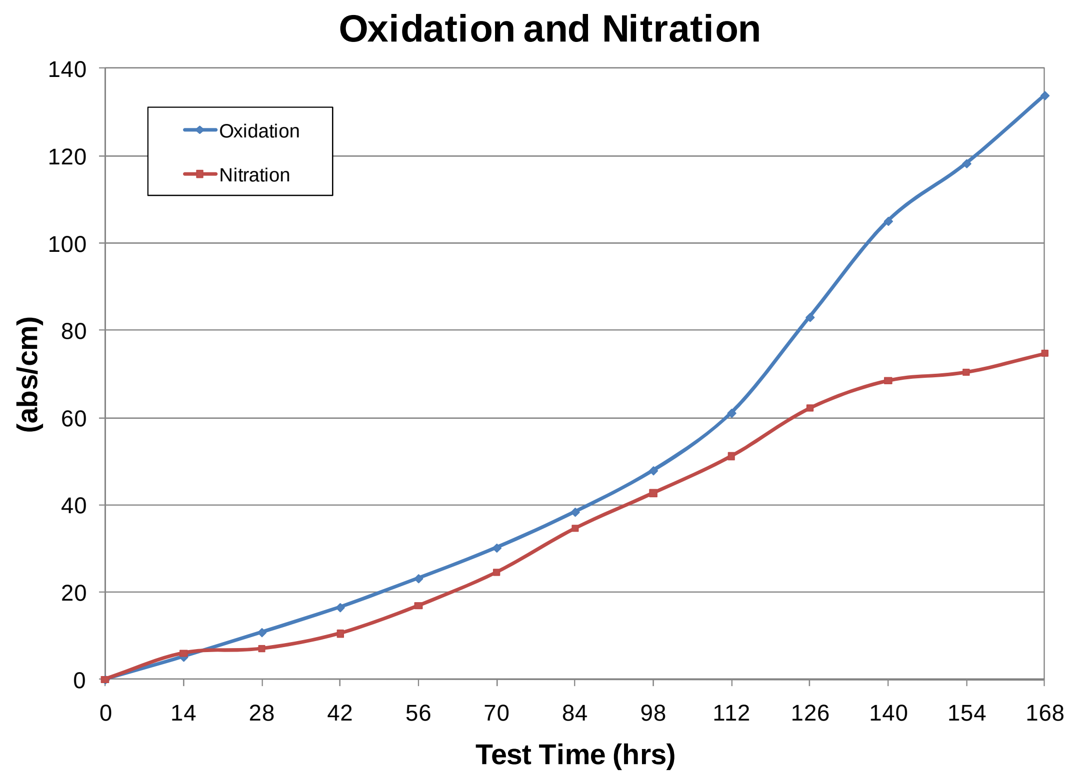


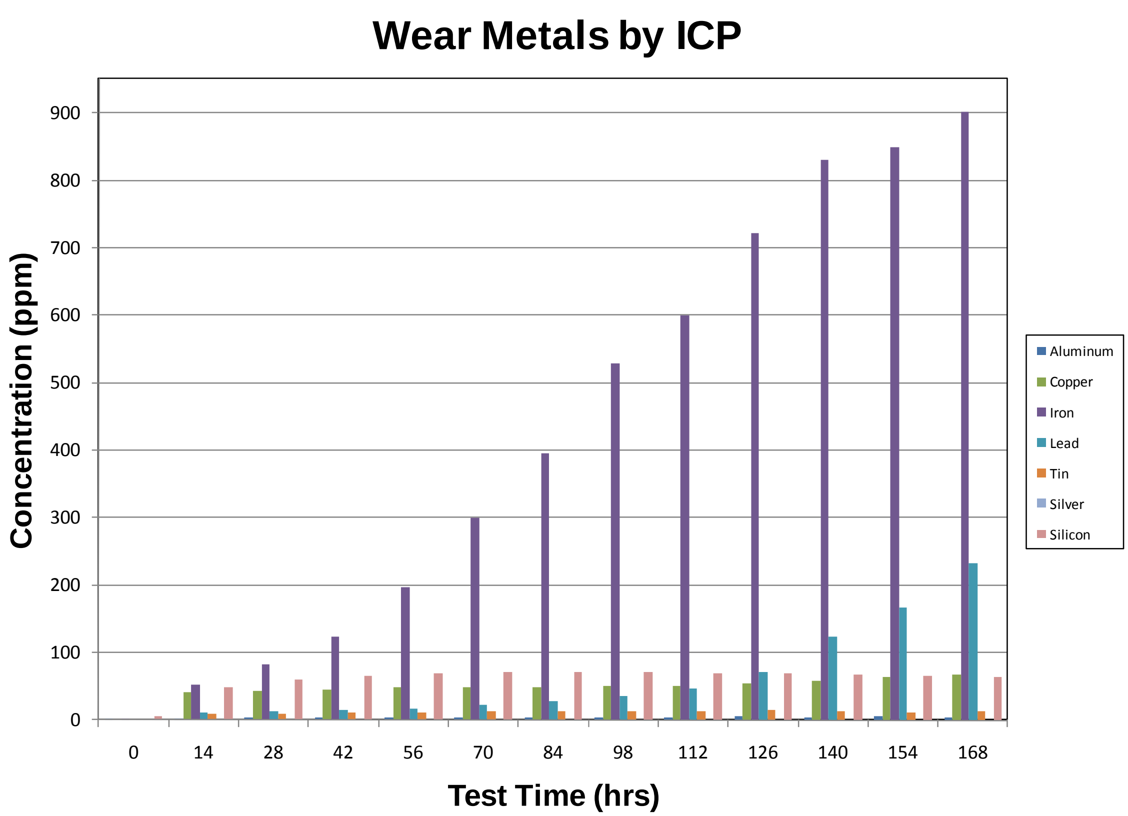




Total Acid and Base Numbers
Total Base Number
Total Acid Number
TAN/TBN (mg KOH/g)
0
1
2
3
4
5
6
7
8
9
10
11
12
0
14
28
42
56
70
84
98
112
126
140
154
168
Test Time (hrs)

Soot
(wt%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
14
28
42
56
70
84
98
112
126
140
154
168
Test Time (hrs)


Oxidation and Nitration
Oxidation
Nitration
(abs/cm)
140
120
100
80
60
40
20
0
0
14
28
42
56
70
84
98
112
126
140
154
168
Test Time (hrs)


Wear Metals by ICP
Concentration (ppm)
900
800
700
600
500
400
300
200
100
0
0
14
28
42
56
70
84
98
112
126
140
154
168
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

Oil Consumption Data

Average oil consumption per test hour was 0.098 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14-hr	1.42	0.22	1.2	1.2
28-hr	1.67	0.23	1.44	2.64
42-hr	1.46	0.21	1.25	3.89
56-hr	1.56	0.24	1.32	5.21
70-hr	1.43	0.24	1.19	6.4
84-hr	1.72	0.24	1.48	7.88
98-hr	1.56	0.24	1.32	9.2
112-hr	1.33	0.24	1.09	10.29
126-hr	1.67	0.26	1.41	11.7
140-hr	2.37	0.25	2.12	13.82
154-hr	1.9	0.25	1.65	15.47
168-hr	1.71	0.24	1.47	16.94
	Initial Fill	15.63	**Total Additions**	19.8
	EOT Drain	16.17	**Total Samples**	2.86

(Initial Fill + Additions)	35.43
(EOT Drain + Samples)	19.03
Total Oil Consumption	16.4

Post Test Engine Ratings

Ratings	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	No	No	No	No	No	No	No	No	--
Ring No.2	No	No	No	No	No	No	No	No	--
Ring No.3	No	No	No	No	No	No	No	No	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	95.00	84.25	97.50	53.50	83.50	50.25	52.25	74.50	73.84
No.2 Groove	0.50	4.25	7.25	3.50	3.50	3.50	11.75	18.75	6.63
No.3 Groove	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.25
No.1 Land	46.25	38.75	40.00	35.50	32.00	38.00	41.00	37.75	38.66
No.2 Land	6.75	14.25	36.00	43.50	7.25	14.75	18.50	18.50	19.94
No.3 Land	0.50	0.00	1.00	2.25	0.50	1.50	0.00	1.25	0.88
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	3.88	2.85	2.24	2.80	2.97	3.88	2.75	1.65	2.88
No.3 Groove	0.20	1.30	1.12	0.77	0.83	3.00	0.96	2.20	1.30
No.1 Land	0.05	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.01
No.2 Land	2.42	0.98	0.36	0.21	2.05	1.16	0.92	0.68	1.10
No.3 Land	1.82	2.32	2.96	2.80	1.98	2.29	1.87	2.42	2.31
Upper Skirt	0.16	0.46	0.32	0.39	0.33	0.43	0.20	0.90	0.40
Under Crown	5.17	4.88	5.70	4.88	4.75	5.51	5.87	7.87	5.58
Front Pin Bore	0.87	1.54	1.54	1.30	1.30	1.30	1.30	1.30	1.31
Rear Pin Bore	0.87	1.54	1.54	0.90	1.30	1.30	1.30	1.30	1.26
Total, Demerits	164.44	157.38	197.53	152.30	142.27	128.88	138.68	169.07	156.32
Miscellanous									
Top Groove Fill, %	95	83	98	54	78	51	40	80	72.38
Intermediate Groove Fill, %	0	1	9	1	1	0	6	12	3.75
Top Land Heavy Carbon, %	29	19	20	14	10	18	22	17	18.63
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0	0	0.00
Valve Tulip Deposits, Merits									
Exahust	8.9	9.4	9.5	9.0	9.0	9.0	9.1	9.0	9.11
Intake	7.6	7.5	7.2	7.6	7.8	7.2	7.6	8.6	7.64

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0547	4.0551	4.0548	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0001	0.0009	0.0005	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0001	0.0005	0.0003	
Piston Skirt Diameter	4.0496	4.0500	4.0499	
Piston Skirt to Cylinder Bore Clearance	0.0047	0.0055	0.0049	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.013	0.015	0.014	
Second Ring	0.031	0.034	0.032	
Oil Control Ring	0.013	0.014	0.013	
Ring To Groove Clearance				
Second Ring	0.0020	0.0020	0.0020	0.0015"-0.003"
Oil Control Ring	0.0020	0.0020	0.0020	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2213	1.2214	1.2213	1.2207"-1.2212"
Piston Pin Clearance	0.0008	0.0009	0.0008	0.0003"-0.0012"
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2212	1.2215	1.2214	1.2207"-1.2212"
Piston Pin Clearance	0.0007	0.0010	0.0009	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0025	0.0030	0.0028	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0030	0.0022	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.006	0.004-0.010"
Rod Side Clearance	0.016	0.016	0.016	0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0549	4.0547		0.0002
	Middle	4.0547	4.0543	4.0547	0.0004
	Bottom	4.0547	4.0545		0.0002
	Taper	0.0002	0.0004		
2	Top	4.0548	4.0544		0.0004
	Middle	4.0548	4.0540	4.0548	0.0008
	Bottom	4.0547	4.0543		0.0004
	Taper	0.0001	0.0004		
3	Top	4.0550	4.0544		0.0006
	Middle	4.0548	4.0541	4.0548	0.0007
	Bottom	4.0547	4.0545		0.0002
	Taper	0.0003	0.0004		
4	Top	4.0548	4.0544		0.0004
	Middle	4.0547	4.0540	4.0548	0.0007
	Bottom	4.0548	4.0544		0.0004
	Taper	0.0001	0.0004		
5	Top	4.0548	4.0542		0.0006
	Middle	4.0548	4.0539	4.0548	0.0009
	Bottom	4.0547	4.0544		0.0003
	Taper	0.0001	0.0005		
6	Top	4.0549	4.0542		0.0007
	Middle	4.0547	4.0539	4.0547	0.0008
	Bottom	4.0546	4.0543		0.0003
	Taper	0.0003	0.0004		
7	Top	4.0553	4.0551		0.0002
	Middle	4.0551	4.0547	4.0551	0.0004
	Bottom	4.0551	4.0550		0.0001
	Taper	0.0002	0.0004		
8	Top	4.0553	4.0549		0.0004
	Middle	4.0552	4.0546	4.0551	0.0006
	Bottom	4.0550	4.0549		0.0001
	Taper	0.0003	0.0003		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0553	4.0547		0.0006
	Middle	4.0550	4.0543	4.0549	0.0007
	Bottom	4.0548	4.0546		0.0002
	Taper	0.0005	0.0004		
2	Top	4.0553	4.0545		0.0008
	Middle	4.0550	4.0542	4.0549	0.0008
	Bottom	4.0548	4.0548		0.0000
	Taper	0.0005	0.0006		
3	Top	4.0554	4.0544		0.0010
	Middle	4.0550	4.0541	4.0549	0.0009
	Bottom	4.0548	4.0547		0.0001
	Taper	0.0006	0.0006		
4	Top	4.0552	4.0547		0.0005
	Middle	4.0550	4.0542	4.0550	0.0008
	Bottom	4.0549	4.0548		0.0001
	Taper	0.0003	0.0006		
5	Top	4.0553	4.0543		0.0010
	Middle	4.0551	4.0541	4.0550	0.0010
	Bottom	4.0549	4.0547		0.0002
	Taper	0.0004	0.0006		
6	Top	4.0554	4.0543		0.0011
	Middle	4.0550	4.0542	4.0550	0.0008
	Bottom	4.0549	4.0546		0.0003
	Taper	0.0005	0.0004		
7	Top	4.0557	4.0553		0.0004
	Middle	4.0555	4.0549	4.0554	0.0006
	Bottom	4.0553	4.0543		0.0010
	Taper	0.0004	0.0010		
8	Top	4.0558	4.0551		0.0007
	Middle	4.0555	4.0547	4.0554	0.0008
	Bottom	4.0553	4.0553		0.0000
	Taper	0.0005	0.0006		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0004	0.0000	
	Middle	0.0003	0.0000	0.0002
	Bottom	0.0001	0.0001	
2	Top	0.0005	0.0001	
	Middle	0.0002	0.0002	0.0001
	Bottom	0.0001	0.0005	
3	Top	0.0004	0.0000	
	Middle	0.0002	0.0000	0.0001
	Bottom	0.0001	0.0002	
4	Top	0.0004	0.0003	
	Middle	0.0003	0.0002	0.0002
	Bottom	0.0001	0.0004	
5	Top	0.0005	0.0001	
	Middle	0.0003	0.0002	0.0002
	Bottom	0.0002	0.0003	
6	Top	0.0005	0.0001	
	Middle	0.0003	0.0003	0.0003
	Bottom	0.0003	0.0003	
7	Top	0.0004	0.0002	
	Middle	0.0004	0.0002	0.0003
	Bottom	0.0002	0.0007	
8	Top	0.0005	0.0002	
	Middle	0.0003	0.0001	0.0003
	Bottom	0.0003	0.0004	
Avgerage All Cylinders	Top	0.0004	0.0001	
	Middle	0.0003	0.0001	
	Bottom	0.0002	0.0004	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3426	0.3430	0.0004	0.3724	0.3738	0.0014
2	0.3427	0.3429	0.0002	0.3725	0.3738	0.0013
3	0.3427	0.3432	0.0005	0.3724	0.3742	0.0018
4	0.3426	0.3429	0.0003	0.3724	0.3736	0.0012
5	0.3425	0.3431	0.0006	0.3725	0.3738	0.0013
6	0.3427	0.3430	0.0003	0.3727	0.3736	0.0009
7	0.3427	0.3429	0.0002	0.3724	0.3736	0.0012
8	0.3427	0.3429	0.0002	0.3725	0.3736	0.0011

Maximum	0.0006
Average	0.0003

Maximum	0.0018
Average	0.0013

Valve Stem Measurement Changes, inches

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3413	0.3412	0.0001	0.3712	0.3712	0.0000
2	0.3413	0.3412	0.0001	0.3712	0.3712	0.0000
3	0.3412	0.3412	0.0000	0.3711	0.3712	-0.0001
4	0.3413	0.3412	0.0001	0.3713	0.3713	0.0000
5	0.3412	0.3412	0.0000	0.3712	0.3712	0.0000
6	0.3412	0.3412	0.0000	0.3712	0.3712	0.0000
7	0.3413	0.3412	0.0001	0.3712	0.3712	0.0000
8	0.3413	0.3412	0.0001	0.3712	0.3712	0.0000

Maximum	0.0001
Average	0.0001

Maximum	0.0000
Average	0.0000

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance Intake			Stem Guide Clearance Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0013	0.0018	0.0005	0.0012	0.0026	0.0014
2	0.0014	0.0017	0.0003	0.0013	0.0026	0.0013
3	0.0015	0.0020	0.0005	0.0013	0.0030	0.0017
4	0.0013	0.0017	0.0004	0.0011	0.0023	0.0012
5	0.0013	0.0019	0.0006	0.0013	0.0026	0.0013
6	0.0015	0.0018	0.0003	0.0015	0.0024	0.0009
7	0.0014	0.0017	0.0003	0.0012	0.0024	0.0012
8	0.0014	0.0017	0.0003	0.0013	0.0024	0.0011

Maximum	0.0006	Maximum	0.0017
Average	0.0004	Average	0.0013

Valve Recession Measurement Changes, inches

	Valve Recession Intake			Valve Recession Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.024	0.057	0.033	0.025	0.070	0.045
2	0.021	0.054	0.033	0.022	0.072	0.050
3	0.022	0.045	0.023	0.022	0.082	0.060
4	0.022	0.050	0.028	0.022	0.078	0.056
5	0.022	0.049	0.027	0.022	0.083	0.061
6	0.023	0.054	0.031	0.024	0.073	0.049
7	0.022	0.060	0.038	0.024	0.073	0.049
8	0.025	0.063	0.038	0.024	0.066	0.042

Maximum	0.038	Maximum	0.061
Average	0.031	Average	0.052

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	1.39
2	1.66
3	1.33
4	1.33
5	1.16
6	1.65
7	1.46
8	1.70
9	1.51
10	1.51
11	1.74
12	1.98
13	1.61
14	2.20
15	2.08
16	2.46

Maximum	2.46
Average	1.67

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0547	4.0500	0.0047
	2	4.0548	4.0499	0.0049
	3	4.0548	4.0500	0.0048
	4	4.0548	4.0499	0.0049
	5	4.0548	4.0499	0.0049
	6	4.0547	4.0499	0.0048
	7	4.0551	4.0500	0.0051
	8	4.0551	4.0496	0.0055
Post - Test	1	4.0549	4.0496	0.0053
	2	4.0549	4.0491	0.0058
	3	4.0549	4.0492	0.0057
	4	4.0550	4.0492	0.0057
	5	4.0550	4.0492	0.0058
	6	4.0550	4.0491	0.0058
	7	4.0554	4.0493	0.0061
	8	4.0554	4.0492	0.0062

Top and Second Ring Radial Wear, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.17980	0.17955	0.00025
	2	0.17940	0.17920	0.00020
	3	0.17920	0.17890	0.00030
	4	0.17780	0.17755	0.00025
	5	0.17895	0.17885	0.00010
2	1	0.17925	0.17910	0.00015
	2	0.17880	0.17865	0.00015
	3	0.17915	0.17890	0.00025
	4	0.17840	0.17800	0.00040
	5	0.17895	0.17870	0.00025
3	1	0.17945	0.17925	0.00020
	2	0.17920	0.17885	0.00035
	3	0.17905	0.17870	0.00035
	4	0.17925	0.17880	0.00045
	5	0.17935	0.17905	0.00030
4	1	0.17940	0.17905	0.00035
	2	0.17975	0.17935	0.00040
	3	0.17915	0.17880	0.00035
	4	0.17790	0.17755	0.00035
	5	0.17925	0.17900	0.00025
5	1	0.17640	0.17595	0.00045
	2	0.17680	0.17635	0.00045
	3	0.17715	0.17680	0.00035
	4	0.17720	0.17700	0.00020
	5	0.17710	0.17690	0.00020
6	1	0.18065	0.18015	0.00050
	2	0.18030	0.17995	0.00035
	3	0.17905	0.17860	0.00045
	4	0.17865	0.17825	0.00040
	5	0.18020	0.17960	0.00060
7	1	0.17690	0.17655	0.00035
	2	0.17900	0.17630	0.00270
	3	0.17880	0.17835	0.00045
	4	0.18055	0.18010	0.00045
	5	0.17850	0.17820	0.00030
8	1	0.17965	0.17920	0.00045
	2	0.17970	0.17925	0.00045
	3	0.17725	0.17670	0.00055
	4	0.17765	0.17715	0.00050
	5	0.17865	0.17815	0.00050

Maximum	0.00270
Average	0.00041

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16205	0.16165	0.00040
	2	0.16215	0.16175	0.00040
	3	0.16210	0.16195	0.00015
	4	0.16255	0.16220	0.00035
	5	0.16225	0.16190	0.00035
2	1	0.16165	0.16125	0.00040
	2	0.16145	0.16120	0.00025
	3	0.16170	0.16130	0.00040
	4	0.16195	0.16170	0.00025
	5	0.16145	0.16115	0.00030
3	1	0.16180	0.16135	0.00045
	2	0.16185	0.16150	0.00035
	3	0.16150	0.16095	0.00055
	4	0.16205	0.16185	0.00020
	5	0.16160	0.16130	0.00030
4	1	0.16185	0.16135	0.00050
	2	0.16240	0.16205	0.00035
	3	0.16235	0.16195	0.00040
	4	0.16275	0.16240	0.00035
	5	0.16195	0.16150	0.00045
5	1	0.16065	0.16035	0.00030
	2	0.16140	0.16095	0.00045
	3	0.16165	0.16120	0.00045
	4	0.16175	0.16145	0.00030
	5	0.16080	0.16030	0.00050
6	1	0.16205	0.16175	0.00030
	2	0.16275	0.16240	0.00035
	3	0.16275	0.16210	0.00065
	4	0.16265	0.16240	0.00025
	5	0.16240	0.16180	0.00060
7	1	0.16150	0.16130	0.00020
	2	0.16210	0.16175	0.00035
	3	0.16190	0.16120	0.00070
	4	0.16185	0.16170	0.00015
	5	0.16155	0.16105	0.00050
8	1	0.16230	0.16175	0.00055
	2	0.16280	0.16245	0.00035
	3	0.16240	0.16200	0.00040
	4	0.16270	0.16215	0.00055
	5	0.16240	0.16165	0.00075

Maximum	0.00075
Average	0.00039

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.015	0.020	0.005
	2	0.031	0.039	0.008
	3	0.013	0.015	0.002
2	1	0.014	0.016	0.002
	2	0.031	0.037	0.006
	3	0.013	0.016	0.003
3	1	0.015	0.019	0.004
	2	0.034	0.038	0.004
	3	0.013	0.014	0.001
4	1	0.014	0.017	0.003
	2	0.032	0.036	0.004
	3	0.013	0.016	0.003
5	1	0.013	0.016	0.003
	2	0.032	0.037	0.005
	3	0.013	0.015	0.002
6	1	0.014	0.018	0.004
	2	0.032	0.036	0.004
	3	0.013	0.016	0.003
7	1	0.014	0.019	0.005
	2	0.034	0.039	0.005
	3	0.014	0.017	0.003
8	1	0.015	0.020	0.005
	2	0.032	0.040	0.008
	3	0.014	0.016	0.002

Ring No. 1 max increase	0.005
Ring No. 2 max increase	0.008
Ring No. 3 max increase	0.003

Ring No. 1 avg increase	0.004
Ring No. 2 avg increase	0.006
Ring No. 3 avg increase	0.002

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.6400	22.5708	0.0692
	2	17.1042	17.0731	0.0311
	3	15.3786	15.3635	0.0151
2	1	22.6755	22.5822	0.0933
	2	16.9650	16.9292	0.0358
	3	15.0861	15.0661	0.0200
3	1	22.7901	22.6769	0.1132
	2	17.1758	17.1317	0.0441
	3	15.3184	15.2955	0.0229
4	1	22.8370	22.7525	0.0845
	2	17.0564	17.0255	0.0309
	3	15.2780	15.2616	0.0164
5	1	22.5980	22.5188	0.0792
	2	16.8943	16.8622	0.0321
	3	15.0738	15.0555	0.0183
6	1	22.8015	22.6941	0.1074
	2	17.1749	17.1377	0.0372
	3	15.0376	15.0181	0.0195
7	1	22.8213	22.7339	0.0874
	2	16.9994	16.9639	0.0355
	3	15.2756	15.2577	0.0179
8	1	22.5662	22.4673	0.0989
	2	17.1372	17.0943	0.0429
	3	15.2120	15.1934	0.0186

Ring No. 1 max decrease	0.1132
Ring No. 2 max decrease	0.0441
Ring No. 3 max decrease	0.0229

Ring No. 1 avg decrease	0.0916
Ring No. 2 avg decrease	0.0362
Ring No. 3 avg decrease	0.0186

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.8618	27.8383	0.0235
	Bottom	27.8388	27.8255	0.0133
2	Top	27.9113	27.8942	0.0171
	Bottom	27.9058	27.8895	0.0163
3	Top	27.7282	27.7134	0.0148
	Bottom	27.7743	27.7594	0.0149
4	Top	27.9100	27.8985	0.0115
	Bottom	27.9072	27.8984	0.0088
5	Top	27.8087	27.7916	0.0171
	Bottom	27.8271	27.8130	0.0141
6	Top	27.8907	27.8779	0.0128
	Bottom	27.8964	27.8871	0.0093
7	Top	27.7650	27.7332	0.0318
	Bottom	27.7907	27.7717	0.0190
8	Top	27.8973	27.8817	0.0156
	Bottom	27.8820	27.8699	0.0121

Maximum	0.0318
Average	0.0158

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	47.8821	47.8538	0.0283
	Bottom	52.6512	52.6236	0.0276
2	Top	47.7610	47.7324	0.0286
	Bottom	52.7404	52.6561	0.0843
3	Top	96.5085	96.2664	0.2421
	Bottom	103.1936	101.7935	1.4001
4	Top	48.1899	48.1699	0.0200
	Bottom	52.6993	52.6460	0.0533
5	Top	68.7850	68.7432	0.0418
	Bottom	72.9468	72.8777	0.0691

Maximum	1.4001
Average	0.1995

<u>**Stanadyne Injection Pump Calibration/Evaluation**</u>

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 15474649**
Test condition :	**AL:**

PUMP RPM	***Description***	***Spec.***	***Before***	***After***	***Change***
1000	Transfer pump psi.	60-62 psi	61	60	1
	Return Fuel	225-375 cc	276	268	8
350	Low Idle	12-16 cc	15	36	21
	Housing psi.	8-12 psi	9	9.5	0.5
	Advance	3.5 deg. min	4.74	4.4	0.34
	Cold Advance Solenoid	0-1 psi.	0	0	0
750	Shut-Off	4 cc max.	0	0	0
900	Fuel Delivery	66.5 - 69.5cc	68	67	1
1600	WOT Fuel delivery	59.5 min.	63	63	0
	WOT Advance	2.5 - 3.5 deg.	2.99	2.41	0.58
	Face Cam Fuel delivery	21.5 - 23.5	22	22	0
	Face Cam Advance	5.25 - 7.25 deg.	7.15	7.46	0.31
	Low Idle	11 - 12 deg.	11.15	10.93	0.22
1825	Fuel Delivery	33 cc min.	39	61	22
1950	High Idle	15 cc max.	1	13	12
	Transfer pump psi.	125 psi max.	103	100	3
200	WOT Fuel Delivery	58 cc min.	61	61	0
	WOT Shut-Off	4 cc max.	0	0	0
75	Low Idle Fuel Delivery	37 cc min.	54	52	2
	Transfer pump psi.	16 psi min.	31	30	1
	Housing psi.	0 -12 psi	6	6	0
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5	-0.5	0
	Fluid Temp. Deg. C				
	Date				

*Pump calibration data to be used for reference only

Photographs

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO250033	**EOT Date:**	11/08/10
Test No.:	LO250033-65T1-W-210	**Test Length:**	168

Piston Skirt Thrust - Best Cyl 6

Piston Skirt Anti-thrust - Best Cyl 6

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO250033	**EOT Date:**	11/08/10
Test No.:	LO250033-65T1-W-210	**Test Length:**	168

Piston Skirt Thrust - Worst Cyl 3

Piston Skirt Anti-thrust - Worst Cyl 3

GEP 6.5 - Wheeled Vehicle Cycle

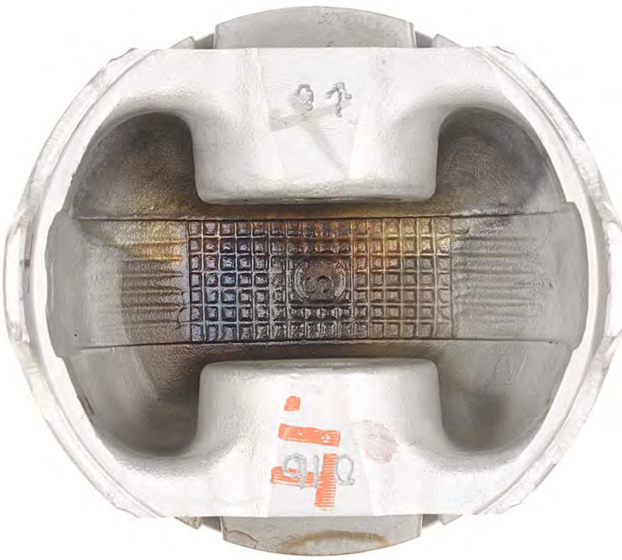
Oil Code:	LO250033	**EOT Date:**	11/08/10
Test No.:	LO250033-65T1-W-210	**Test Length:**	168

Piston Rings - Best Cyl 1

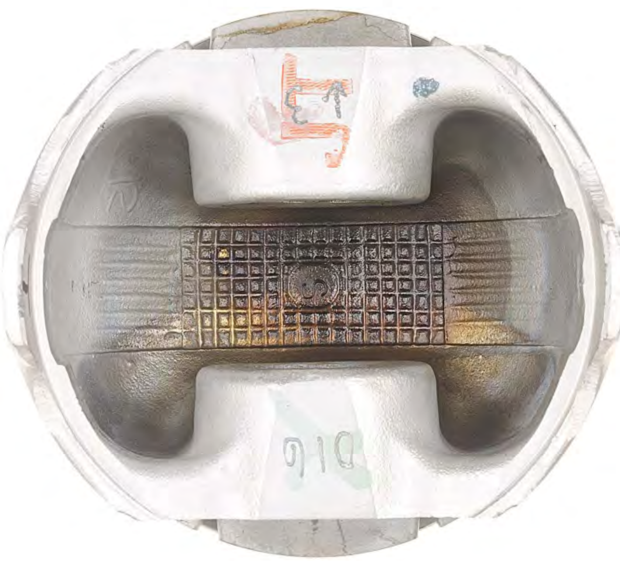
Piston Rings - Worst Cyl 3

Oil Code:	LO250033	EOT Date:	11/08/10
Test No.:	LO250033-65T1-W-210	Test Length:	168

Piston Undercrown - Best Cyl 6



Piston Undercrown - Worst Cyl 3



Oil Code:	LO250033	EOT Date:	11/08/10
Test No.:	LO250033-65T1-W-210	Test Length:	168

Engine Block Cylinder Bore - Best Cyl 1

Engine Block Cylinder Bore - Worst Cyl 6

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO250033	**EOT Date:**	11/08/10
Test No.:	LO250033-65T1-W-210	**Test Length:**	168

Exhaust and Intake Valve - Best Cyl 8

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO250033	**EOT Date:**	11/08/10
Test No.:	LO250033-65T1-W-210	**Test Length:**	168

Exhaust and Intake Valve - Worst Cyl 6

Oil Code:	LO250033	**EOT Date:**	11/08/10
Test No.:	LO250033-65T1-W-210	**Test Length:**	168

Rod Bearings

Oil Code:	LO250033	**EOT Date:**	11/08/10
Test No.:	LO250033-65T1-W-210	**Test Length:**	168

Main Bearings

APPENDIX C4. – EVALUATION OF LO251746 IN THE 6.5L(T) HIGH TEMPERATURE OIL ENDURANCE TEST

EVALUATION OF SCPL CANDIDATE LO-251746

Project 14734.01

GEP 6.5L Turbocharged HMMWV Engine

Test Lubricant: LO-251746
Test Fuel: Jet-A w/DCI-4A
Test Number: LO251746-65T1-W-210
Start of Test Date: June 23, 2010
End of Test Date: July 9, 2010
Test Duration: 168 Hours
Test Procedure: Tactical Wheeled Vehicle

Conducted for

U.S. Army TARDEC
Force Projection Technologies
Warren, Michigan

Introduction

This test was used to determine the performance of Single Common Powertrain Lubricant (SCPL) candidate LO-251746 when used in the General Engine Products (GEP) 6.5L turbocharged engine by the procedures outlined in the Tactical Wheeled Vehicle Cycle (CRC Report No.406, Development of Military Fuel/Lubricant/Engine Compatibility Test). This work was completed in support of Project 14734.01, Single Common Powertrain Lubricants for Combat/Tactical Equipment.

Test Engine

The oil was evaluated in the General Engine Products 6.5L turbocharged diesel engine, representative of engines currently fielded in High Mobility Multipurpose Wheeled Vehicles (HMMWV). Prior to testing the engine was disassembled and measured for pre-test wear, engine clearances and specifications were verified, and the engine was reassembled following standard assembly procedures.

Test Stand Configuration

The engine was mounted in a test stand specifically configured for GEP engine testing. Engine monitoring, control, and data acquisition was supplied by Southwest Research Institute (SwRI) developed PRISM software. An appropriately sized absorption dynamometer was used to supply engine loading. Engine oil and coolant temperatures were controlled with the use of liquid-to-liquid heat exchangers. Engine intake air was supplied at ambient conditions, and inlet fuel temperatures were controlled through an auxiliary fuel heater loop.

Engine Run-in

Prior to testing, the engine was run-in following procedures outlined below. Cyclic modes were repeated for a total of 24 cycles. Total runtime for engine run-in was approximately 6 hours.

Time, min	Mode	Speed, RPM	Torque, lb*ft	Coolant Out, °F	Oil Galley, °F
10	Steady State	1500	10	215	220
10	Steady State	1600	109	215	220
10	Steady State	2400	145	215	220
10	Steady State	3200	165	215	220
1	Cyclic	900	0	215	220
2	Cyclic	2600	50%	215	220
2	Cyclic	1800	1%	215	220
2	Cyclic	1200	25%	215	220
2	Cyclic	1800	50%	215	220
2	Cyclic	3200	5%	215	220
2	Cyclic	2200	50%	215	220

Figure 1 - Test Engine Run-In Procedure

Pre-Test Engine Performance Check

After completion of engine run-in, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine pre-test engine performance. The pre-test engine performance check was completed using the same oil charge used during the engine run-in segment. Powercurve plots can be seen in the Engine Performance Curves section.

Test Cycle

The test cycle followed during oil evaluation was the standard 210 hr Tactical Wheeled Vehicle cycle as outlined in CRC Report No. 406, Development of Military Fuel/Lubricant/Engine Compatibility Test. Test termination would occur at 210 hrs or upon major oil degradation, which ever occurred first. The test cycle consists of cyclic modes alternating between 2 hr rated speed conditions and 1 hr idle soaks. Total daily run-time was 14 hrs, 10 hrs at rated and 4 hrs at idle, with a 10 hr soak overnight before resuming the next days testing. Engine oil temperatures were elevated to simulate conditions consistent with high ambient temperature typical of desert operations. Engine operating parameters were controlled throughout testing as specified in the table below.

Parameter	Rated Speed	Idle
Engine Speed, RPM	3400 +/- 25	900 +/- 25
Water Jacket Out, °F	204 +/- 5	100 +/- 5
Oil Sump, °F	260 +/- 5	125 +/- 5

Figure 2 - Test Cycle Operating Parameters

Engine coolant was a 60/40 blend of ethylene glycol antifreeze and deionized water. Test fuel was JP8 blended onsite from Jet-A with double the max treat rate of corrosion inhibitor/lubricity enhancer DCI-4A.

Oil Sampling

Four ounces of engine oil was sampled every 14 hrs for used oil analysis. Engine oil analysis consisted of the following tests: (Note – at every 70 hr interval, two additional tests were completed on the used oil as shown below). All oil samples were weighed and logged to take into account during calculations of total engine oil consumption for the test duration.

Every 14hrs		
ASTM	**D4739**	Total Base Number
ASTM	**D664**	Total Acid Number
ASTM	**D445**	Kinematic Viscosity @ 100°C
ASTM	**API Gravity**	API Gravity
ASTM	**D4052**	Density
ASTM	**TGA SOOT**	TGA Soot
ASTM	**E168**	Oxidation
ASTM	**E168**	Nitration
ASTM	**D5185**	Wear Metals by ICP

Every 70hrs		
ASTM	**D445**	Kinematic Viscosity @ 40°C
ASTM	**D2270**	Kinematic Viscosity Index

Figure 3 - Used Oil Analysis Procedures

Used oil analysis results can be seen in the engine oil analysis and engine oil analysis trends section of the report.

Oil Level Checks

Engine oil level was checked daily and replenished as needed to restore oil level to full mark. This process occurred after the completion of the 10hr soak, prior to restarting the test. All oil

additions were weighed and logged to take into account during calculation of total engine oil consumption for the test duration.

Post-Test Engine Performance Check

After completion of testing, a full load powercurve was completed from 1000 rpm to rated engine speed (3400 rpm) to determine post-test engine performance. The post-test engine performance check was completed using the same oil charge used during the testing segment. Powercurve plots can be seen in the Engine Performance Curves section.

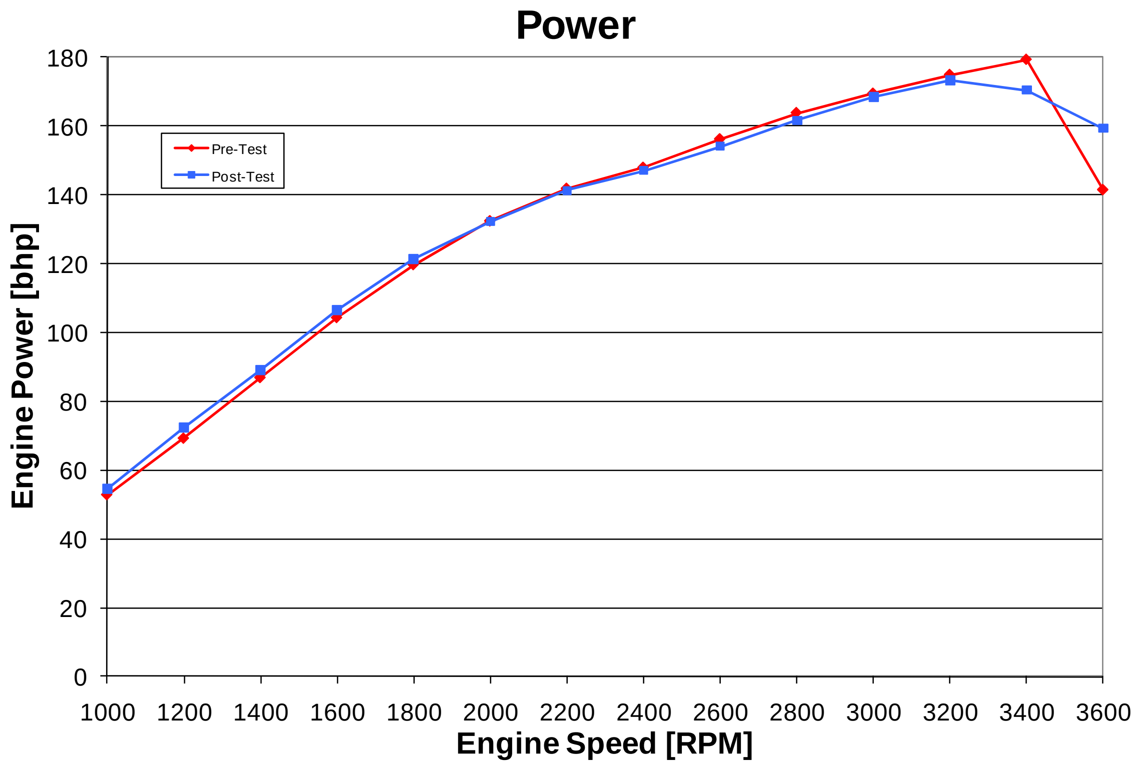
Engine Operating Conditions Summary

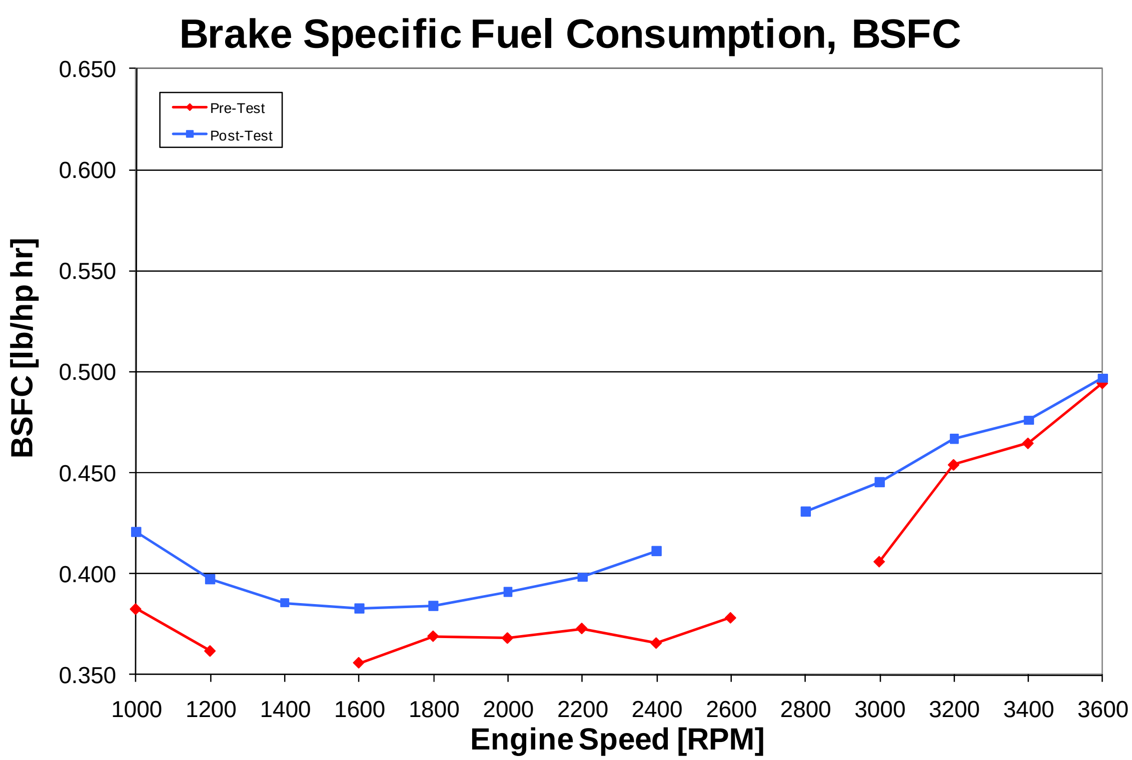
Below is a summary of the engine operating conditions over the test duration. Testing was stopped at 168hrs due to oil degradation.

		Rated Conditions (3400 RPM)		Idle Conditions (900 RPM)	
Perameter:	**Units:**	**Average**	**Std. Dev.**	**Average**	**Std. Dev.**
Engine Speed	RPM	3400.00	0.72	900.16	2.05
Torque*	ft*lb	256.24	1.74	34.69	4.91
Fuel Flow	lb/hr	77.86	0.89	5.03	0.32
Power*	bhp	165.88	1.11	5.95	0.86
BSFC*	lb/bhp*hr	0.469	0.006	0.851	0.050
Temperatures:					
Coolant In	°F	191.39	0.73	92.63	0.50
Coolant Out	°F	204.99	0.66	100.00	0.41
Oil Sump	°F	259.96	0.37	125.40	1.30
Fuel In	°F	95.01	0.33	94.98	0.34
Intake Air	°F	69.95	2.24	66.71	2.31
Cylinder 1 Exhaust	°F	1098.38	14.59	206.81	7.68
Cylinder 2 Exhaust	°F	1158.88	18.88	189.30	8.81
Cylinder 3 Exhaust	°F	1224.78	31.99	202.35	7.45
Cylinder 4 Exhaust	°F	1115.13	16.48	197.00	8.40
Cylinder 5 Exhaust	°F	1181.29	25.83	192.15	8.52
Cylinder 6 Exhaust	°F	1118.51	17.07	195.04	8.35
Cylinder 7 Exhaust	°F	1123.50	19.87	178.79	7.68
Cylinder 8 Exhaust	°F	1144.84	18.46	193.17	7.78
Pressures:					
Oil Galley	psi	37.13	0.99	35.88	5.25
Ambient Pressure	psiA	14.23	0.04	14.23	0.04
Boost Pressure	psi	3.96	0.09	-0.17	0.06

* Non-corrected Values

Engine Performance Curves



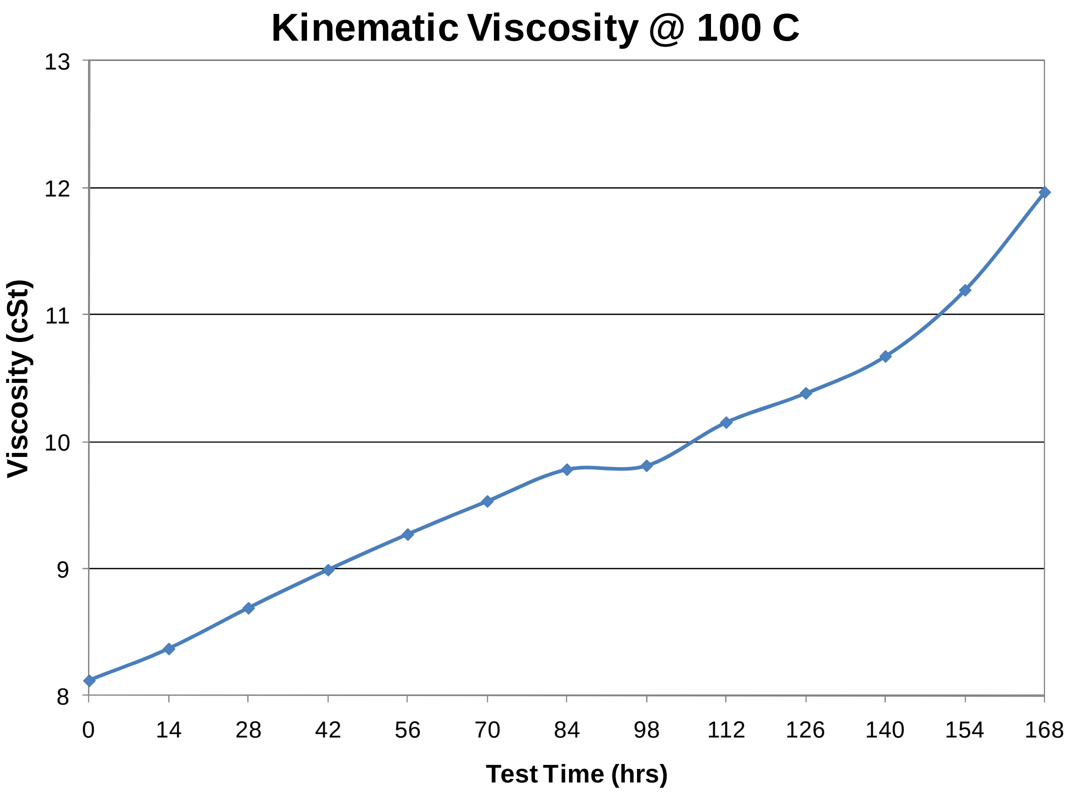


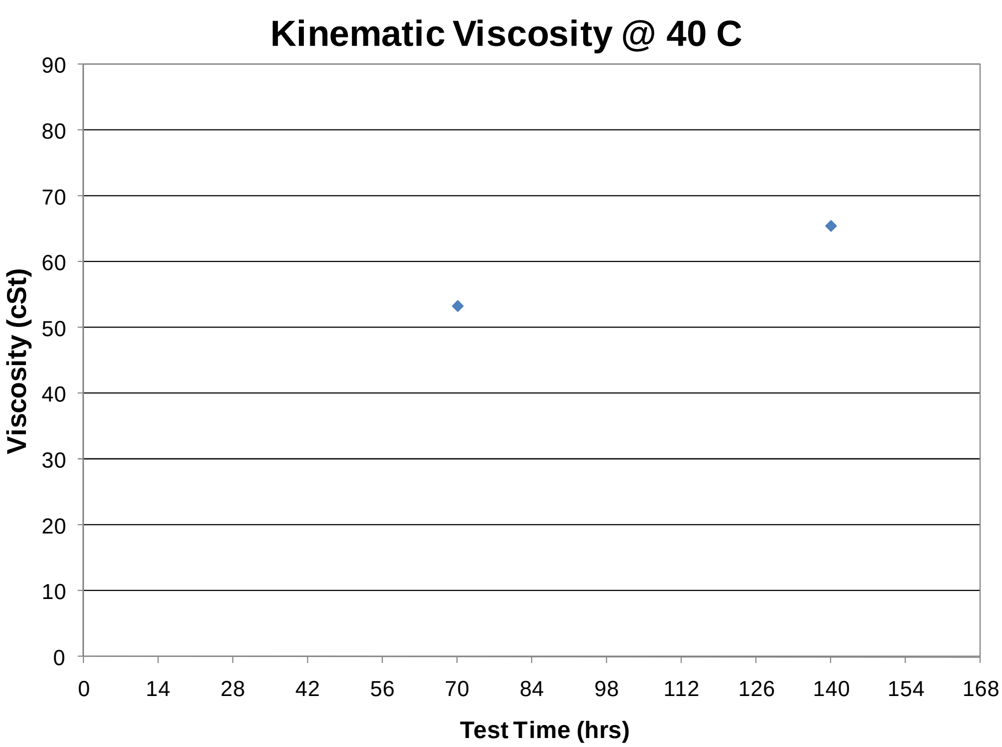
*Note – Breaks in BSFC plot due to invalid values for engine fuel flow during powercurve.

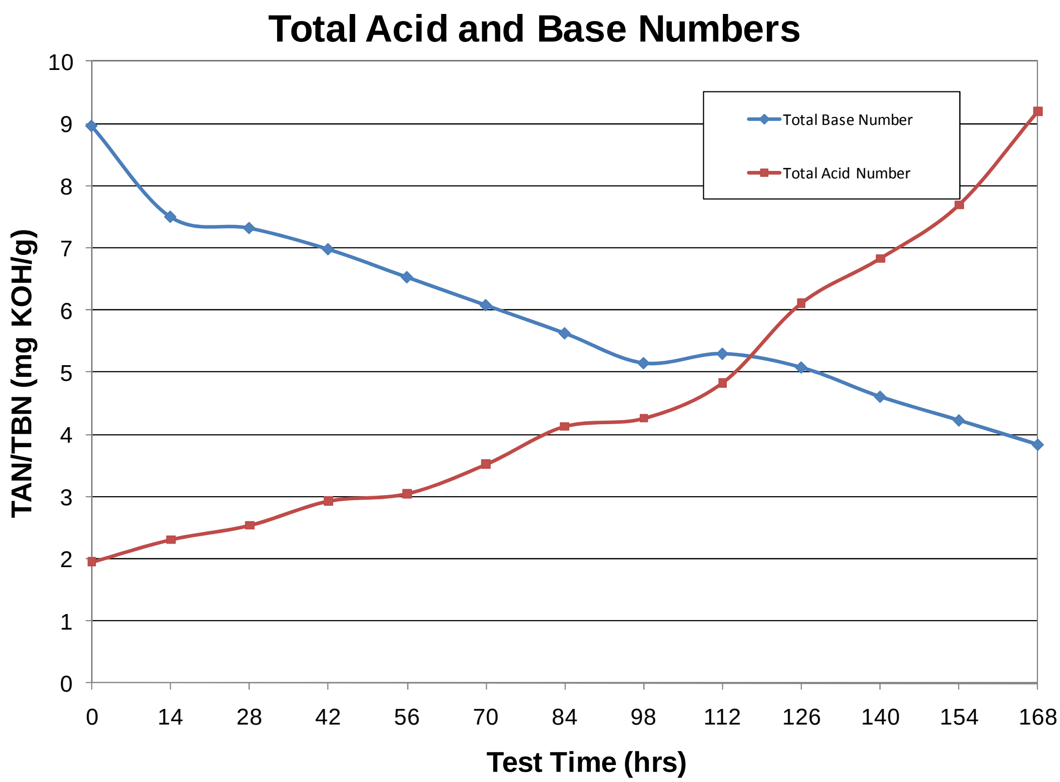
Engine Oil Analysis

Property	ASTM Test	Test Hours												
		0	14	28	42	56	70	84	98	112	126	140	154	168
Density	D4052	0.8452	0.8484	0.8508	0.853	0.8551	0.8575	0.8546	0.8621	0.8645	0.8684	0.8732	0.8791	0.8859
Viscosity @ 100°C (cSt)	D445	8.1	8.4	8.7	9.0	9.3	9.5	9.8	9.8	10.2	10.4	10.7	11.19	11.96
Viscosity @ 40°C (cSt)	D445						53.3					65.4		
Viscosity Index (dyne/cm)	D2270						168.0					153.0		
Total Base Number (mg KOH/g)	D4739	9.0	7.5	7.3	7.0	6.5	6.1	5.6	5.2	5.3	5.1	4.6	4.23	3.84
Total Acid Number (mg KOH/g)	D664	2.0	2.3	2.5	2.9	3.1	3.5	4.1	4.3	4.8	6.1	6.8	7.69	9.19
Oxidation (Abs./cm)	E168 FTNG	0.0	5.8	10.0	14.4	18.7	23.5	28.7	33.3	38.5	48.2	61.2	78.56	99.08
Nitration (Abs./cm)	E168 FTNG	0.0	4.7	5.6	5.6	7.7	10.6	14.7	18.1	22.4	31.4	40.2	46.86	52.77
Soot	Soot	0.2	0.5	0.6	0.8	0.8	1.0	1.1	1.4	1.4	1.7	2.0	2.265	2.597
Wear Metals (ppm)	D5185													
Al		2	4	4	4	4	5	5	5	5	5	5	5	6
Sb		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ba		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
B		69	57	54	53	51	52	53	53	51	55	55	56	55
Ca		782	885	867	964	1001	1003	1018	1040	1063	1135	1181	1176	1183
Cr		<1	2	2	3	3	4	4	5	5	6	6	6	7
Cu		<1	25	27	29	31	33	34	34	36	37	39	44	48
Fe		2	60	98	126	160	188	220	240	278	322	368	466	541
Pb		<1	22	24	27	28	31	35	38	40	51	68	101	152
Mg		1155	1229	1226	1345	1408	1433	1477	1516	1501	1596	1612	1675	1669
Mn		<1	2	2	3	3	3	4	4	4	5	5	6	7
Mo		65	79	85	92	94	100	106	110	108	118	120	123	124
Ni		<1	2	3	4	5	5	6	6	7	8	8	9	9
P		1061	1043	1031	1030	1101	1088	1123	1149	1169	1196	1235	1273	1318
Si		6	47	57	62	63	62	62	58	55	59	57	55	53
Ag		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Na		5	6	8	<5	8	6	11	6	10	10	7	8	12
Sn		<1	11	13	14	15	15	17	16	16	18	17	18	18
Zn		1236	1262	1308	1335	1403	1448	1498	1519	1581	1622	1645	1697	1780
K		<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Sr		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
V		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ti		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Cd		<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

Engine Oil Analysis Trends

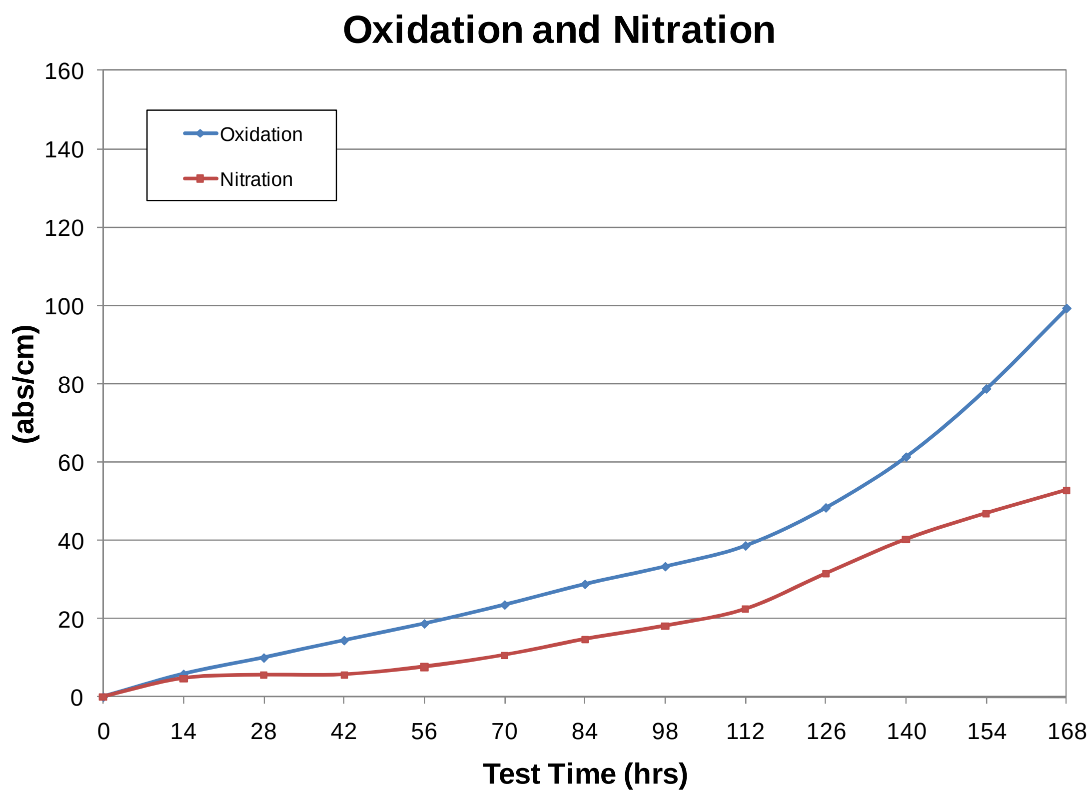


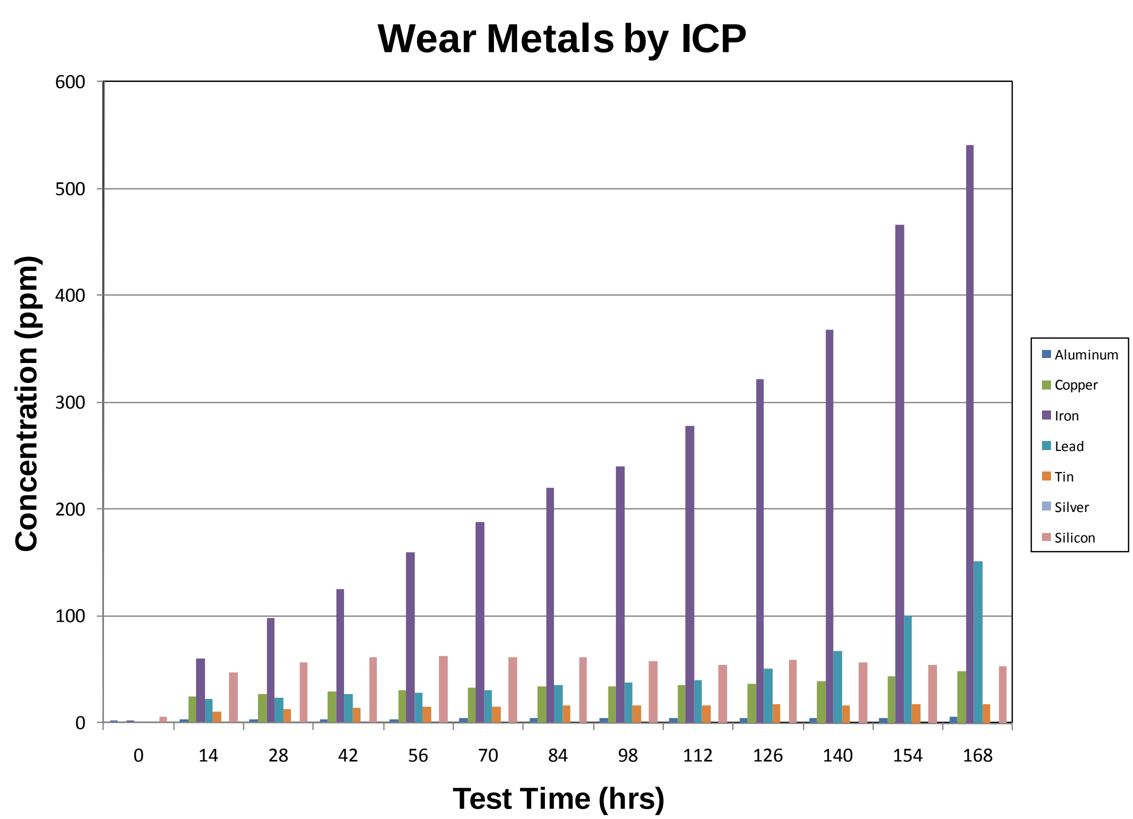




Total Acid and Base Numbers
Total Base Number
Total Acid Number
TAN/TBN (mg KOH/g)
10
9
8
7
6
5
4
3
2
1
0
0
14
28
42
56
70
84
98
112
126
140
154
168
Test Time (hrs)

Soot
(wt%)
2.5
2.0
1.5
1.0
0.5
0.0
0
14
28
42
56
70
84
98
112
126
140
154
168
Test Time (hrs)


Oxidation and Nitration
Oxidation
Nitration
(abs/cm)
160
140
120
100
80
60
40
20
0
0
14
28
42
56
70
84
98
112
126
140
154
168
Test Time (hrs)


Wear Metals by ICP
Concentration (ppm)
600
500
400
300
200
100
0
0
14
28
42
56
70
84
98
112
126
140
154
168
Test Time (hrs)
Aluminum
Copper
Iron
Lead
Tin
Silver
Silicon

Oil Consumption Data

Average oil consumption per test hour was 0.072 lbs/hr.

	Additions (lbs)	Samples (lbs)	Consumption (lbs)	Consumption Accumulated
14-hr	1.05	0.23	0.82	0.82
28-hr	1.1	0.24	0.86	1.68
42-hr	1.58	0.23	1.35	3.03
56-hr	1.2	0.22	0.98	4.01
70-hr	1.24	0.22	1.02	5.03
84-hr	1.56	0.23	1.33	6.36
98-hr	1.48	0.23	1.25	7.61
112-hr	0.84	0.24	0.6	8.21
126-hr	1.04	0.23	0.81	9.02
140-hr	0.93	0.24	0.69	9.71
154-hr	1.1	0.24	0.86	10.57
168-hr	1.2	0.25	0.95	11.52

Initial Fill	12.89	**Total Additions**	14.32
EOT Drain	12.34	**Total Samples**	2.8

(Initial Fill + Additions)	27.21
(EOT Drain + Samples)	15.14
Total Oil Consumption	12.07

Post Test Engine Ratings

Ratings	Cylinder Number								
	1	2	3	4	5	6	7	8	Avg
Ring Sticking									
Ring No.1	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.2	NO	NO	NO	NO	NO	NO	NO	NO	--
Ring No.3	NO	NO	NO	NO	NO	NO	NO	NO	--
Scuffing % Area									
Ring No.1	0	0	0	0	0	0	0	0	0.00
Ring No.2	0	0	0	0	0	0	0	0	0.00
Ring No.3	0	0	0	0	0	0	0	0	0.00
Piston Crown	0	0	0	0	0	0	0	0	0.00
Piston Skirt	0	0	0	0	0	0	0	0	0.00
Cylinder Liner, %	0	0	0	0	0	0	0	0	0.00
Piston Carbon, Demerits									
No.1 Groove	35.25	28.50	34.50	43.50	32.75	35.00	40.50	40.25	36.28
No.2 Groove	20.50	1.25	10.00	0.00	3.75	0.00	10.00	1.25	5.84
No.3 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.1 Land	38.00	29.00	36.50	43.25	38.25	38.75	34.25	32.50	36.31
No.2 Land	15.50	6.75	15.25	5.50	16.00	5.50	29.50	20.00	14.25
No.3 Land	0.00	0.00	4.00	1.50	0.50	1.00	0.00	0.00	0.88
Upper Skirt	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Under Crown	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Front Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Rear Pin Bore	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Piston Lacquer, Demerits									
No.1 Groove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
No.2 Groove	0.81	3.47	2.82	3.25	2.45	3.97	1.38	3.72	2.73
No.3 Groove	0.86	1.42	1.42	1.58	1.45	1.56	0.34	2.62	1.41
No.1 Land	0.07	0.02	0.02	0.02	0.02	0.01	0.01	0.00	0.02
No.2 Land	2.85	3.66	1.39	2.12	1.91	3.72	0.57	1.39	2.20
No.3 Land	1.15	1.80	1.32	0.75	0.31	1.83	0.20	2.32	1.21
Upper Skirt	0.25	0.60	0.87	0.33	0.20	0.33	0.20	1.50	0.54
Under Crown	4.43	3.12	4.74	4.05	3.53	4.45	6.07	7.75	4.77
Front Pin Bore	0.60	0.63	2.20	0.63	0.55	0.60	0.55	0.60	0.80
Rear Pin Bore	0.60	1.75	0.64	0.63	0.55	0.60	0.57	0.60	0.74
Total, Demerits	120.87	81.97	115.67	107.11	102.22	97.32	124.14	114.50	107.98
Miscellanous									
Top Groove Fill, %	25	24	29	29	22	29	41	29	28.50
Intermediate Groove Fill, %	4	1	7	0	1	0	4	0	2.13
Top Land Heavy Carbon, %	22	6	17	25	19	19	13	10	16.38
Top Lan Flaked Carbon, %	0	0	0	0	0	0	0	0	0.00
Valve Tulip Deposits, Merits									
Exahust	9.0	8.9	9.0	9.0	9.0	9.0	8.9	9.5	9.04
Intake	9.1	8.6	9.0	9.5	7.8	9.1	7.6	8.1	8.60

Engine Measurement Changes

Engine Rebuild Measurements, inches

Cylinder Bore	Minimum	Maximum	Average	Spec:
Inside Diameter	4.0548	4.0555	4.0550	Cylinder 1 thru 6 ID 4.054"-4.075"
Out of Round	0.0001	0.0011	0.0006	Cylinder 7 thru 8 ID 4.055"-Maximum 0.008"
Taper	0.0001	0.0005	0.0003	
Piston Skirt Diameter	4.0496	4.0499	4.0497	
Piston Skirt to Cylinder Bore Clearance	0.0049	0.0059	0.0053	Cylinder 1 thru 7 0.003"-0.004" Cylinder 7 thru 8 0.004"-0.005"
Piston Ring End Gaps				
Top Ring	0.015	0.018	0.017	
Second Ring	0.038	0.039	0.038	
Oil Control Ring	0.020	0.020	0.020	
Ring To Groove Clearance				
Second Ring	0.0020	0.0020	0.0020	0.0015"-0.003"
Oil Control Ring	0.0020	0.0020	0.0020	0.0015"-0.0035"
Piston Pin				
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Piston)	1.2213	1.2213	1.2213	1.2207"-1.2212"
Piston Pin Clearance	0.0008	0.0008	0.0008	0.0003"-0.0012"
Piston Pin Diameter	1.2205	1.2205	1.2205	1.2203"-1.2206"
Pin Bore Diameter (Rod)	1.2213	1.2214	1.2213	1.2207"-1.2212"
Piston Pin Clearance	0.0008	0.0009	0.0008	0.0003"-0.0012"
Bearing Clerances				
Connecting Rod to Journal	0.0020	0.0025	0.0023	0.0017"-0.0039"
Main Bearing to Journa	0.0020	0.0025	0.0021	0.001"-0.005"
Crankshaft Endplay				
Crankshaft Endplay	N/A	N/A	0.006	0.004-0.010"
Rod Side Clearance	0.009	0.010	0.010	0.007-0.024"

Note: Referenced specifications are to 1994 General Motors Light Duty Truck guidelines. Some variation in engine specifications are expected between updated versions of the GEP 6.5L(T) engines used by the military and those used previously by General Motors. GEP engine specifications are not public infomrmation. GM specifications serve only as guielines to acess the pre-test engine condition for fit for purpose.

Pre-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0548	4.0544		0.0004
	Middle	4.0547	4.0548	4.0548	0.0001
	Bottom	4.0548	4.0543		0.0005
	Taper	0.0001	0.0005		
2	Top	4.0548	4.0546		0.0002
	Middle	4.0548	4.0541	4.0548	0.0007
	Bottom	4.0547	4.0544		0.0003
	Taper	0.0001	0.0005		
3	Top	4.0551	4.0543		0.0008
	Middle	4.0550	4.0540	4.0549	0.0010
	Bottom	4.0548	4.0544		0.0004
	Taper	0.0003	0.0004		
4	Top	4.0549	4.0544		0.0005
	Middle	4.0549	4.0540	4.0549	0.0009
	Bottom	4.0548	4.0544		0.0004
	Taper	0.0001	0.0004		
5	Top	4.0552	4.0545		0.0007
	Middle	4.0551	4.0541	4.0551	0.0010
	Bottom	4.0550	4.0545		0.0005
	Taper	0.0002	0.0004		
6	Top	4.0551	4.0545		0.0006
	Middle	4.0550	4.0542	4.0550	0.0008
	Bottom	4.0549	4.0546		0.0003
	Taper	0.0002	0.0004		
7	Top	4.0555	4.0551		0.0004
	Middle	4.0555	4.0548	4.0555	0.0007
	Bottom	4.0554	4.0549		0.0005
	Taper	0.0001	0.0003		
8	Top	4.0556	4.0550		0.0006
	Middle	4.0556	4.0545	4.0555	0.0011
	Bottom	4.0554	4.0549		0.0005
	Taper	0.0002	0.0005		

Post-Test Cylinder Bore Measurements, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. (ABD), (TD@MID + TD@BOT)/2	Out of Round
1	Top	4.0551	4.0545		0.0006
	Middle	4.0548	4.0540	4.0548	0.0008
	Bottom	4.0548	4.0545		0.0003
	Taper	0.0003	0.0005		
2	Top	4.0552	4.0545		0.0007
	Middle	4.0549	4.0542	4.0548	0.0007
	Bottom	4.0546	4.0546		0.0000
	Taper	0.0006	0.0004		
3	Top	4.0553	4.0543		0.0010
	Middle	4.0550	4.0540	4.0550	0.0010
	Bottom	4.0549	4.0545		0.0004
	Taper	0.0004	0.0005		
4	Top	4.0551	4.0545		0.0006
	Middle	4.0549	4.0540	4.0548	0.0009
	Bottom	4.0547	4.0546		0.0001
	Taper	0.0004	0.0006		
5	Top	4.0555	4.0544		0.0011
	Middle	4.0557	4.0540	4.0553	0.0017
	Bottom	4.0549	4.0546		0.0003
	Taper	0.0008	0.0006		
6	Top	4.0556	4.0545		0.0011
	Middle	4.0552	4.0542	4.0551	0.0010
	Bottom	4.0549	4.0547		0.0002
	Taper	0.0007	0.0005		
7	Top	4.0557	4.0552		0.0005
	Middle	4.0555	4.0549	4.0554	0.0006
	Bottom	4.0552	4.0552		0.0000
	Taper	0.0005	0.0003		
8	Top	4.0558	4.0554		0.0004
	Middle	4.0555	4.0549	4.0555	0.0006
	Bottom	4.0554	4.0553		0.0001
	Taper	0.0004	0.0005		

Cylinder Bore Diameter Changes, inches

Cylinder	Depth	Tranverse (TD)	Longitude (LD)	Avg Bore Dia. Change (TD@MID + TD@BOT)/2
1	Top	0.0003	0.0001	
	Middle	0.0001	0.0008	0.0000
	Bottom	0.0000	0.0002	
2	Top	0.0004	0.0001	
	Middle	0.0001	0.0001	0.0001
	Bottom	0.0001	0.0002	
3	Top	0.0002	0.0000	
	Middle	0.0000	0.0000	0.0001
	Bottom	0.0001	0.0001	
4	Top	0.0002	0.0001	
	Middle	0.0000	0.0000	0.0000
	Bottom	0.0001	0.0002	
5	Top	0.0003	0.0001	
	Middle	0.0006	0.0001	0.0003
	Bottom	0.0001	0.0001	
6	Top	0.0005	0.0000	
	Middle	0.0002	0.0000	0.0001
	Bottom	0.0000	0.0001	
7	Top	0.0002	0.0001	
	Middle	0.0000	0.0001	0.0001
	Bottom	0.0002	0.0003	
8	Top	0.0002	0.0004	
	Middle	0.0001	0.0004	0.0000
	Bottom	0.0000	0.0004	
Avgerage All Cylinders	Top	0.0003	0.0001	
	Middle	0.0001	0.0002	
	Bottom	0.0001	0.0002	

Valve Guide Measurement Changes, inches

	Valve Guide Diameter Intake			Valve Guide Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3430	0.3435	0.0005	0.3733	0.3738	0.0005
2	0.3430	0.3435	0.0005	0.3733	0.3743	0.0010
3	0.3430	0.3435	0.0005	0.3733	0.3738	0.0005
4	0.3430	0.3448	0.0018	0.3734	0.3743	0.0009
5	0.3430	0.3435	0.0005	0.3733	0.3738	0.0005
6	0.3430	0.3446	0.0016	0.3733	0.3748	0.0015
7	0.3430	0.3435	0.0005	0.3734	0.3738	0.0004
8	0.3430	0.3435	0.0005	0.3733	0.3738	0.0005

Maximum	0.0018
Average	0.0008

Maximum	0.0015
Average	0.0007

Valve Stem Measurement Changes, inches

	Valve Stem Diameter Intake			Valve Stem Diameter Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.3416	0.3411	0.0005	0.3709	0.3708	0.0001
2	0.3414	0.3412	0.0002	0.3709	0.3709	0.0000
3	0.3414	0.3411	0.0003	0.3708	0.3708	0.0000
4	0.3414	0.3410	0.0004	0.3709	0.3708	0.0001
5	0.3416	0.3413	0.0003	0.3709	0.3708	0.0001
6	0.3416	0.3412	0.0004	0.3708	0.3707	0.0001
7	0.3414	0.3411	0.0003	0.3708	0.3707	0.0001
8	0.3418	0.3412	0.0006	0.3709	0.3708	0.0001

Maximum	0.0006
Average	0.0004

Maximum	0.0001
Average	0.0001

Valve Stem to Guide Clearance Changes, inches

	Stem/Guide Clearance Intake			Stem Guide Clearance Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.0014	0.0024	0.0010	0.0024	0.0030	0.0006
2	0.0016	0.0023	0.0007	0.0024	0.0034	0.0010
3	0.0016	0.0024	0.0008	0.0025	0.0030	0.0005
4	0.0016	0.0038	0.0022	0.0025	0.0035	0.0010
5	0.0014	0.0022	0.0008	0.0024	0.0030	0.0006
6	0.0014	0.0034	0.0020	0.0025	0.0041	0.0016
7	0.0016	0.0024	0.0008	0.0026	0.0031	0.0005
8	0.0012	0.0023	0.0011	0.0024	0.0030	0.0006

Maximum	0.0022
Average	0.0012

Maximum	0.0016
Average	0.0008

Valve Recession Measurement Changes, inches

	Valve Recession Intake			Valve Recession Exahust		
Cylinder	Before	After	Change	Before	After	Change
1	0.028	0.061	0.033	0.025	0.063	0.038
2	0.026	0.053	0.027	0.022	0.063	0.040
3	0.029	0.056	0.027	0.025	0.078	0.053
4	0.026	0.064	0.038	0.021	0.042	0.020
5	0.027	0.063	0.036	0.025	0.069	0.045
6	0.026	0.061	0.036	0.023	0.050	0.027
7	0.029	0.059	0.031	0.026	0.049	0.022
8	0.026	0.055	0.030	0.026	0.034	0.008

Maximum	0.038
Average	0.032

Maximum	0.053
Average	0.032

Post-Test Cam Lobe Profile, µm

Cam Lobe	Waviness Parameter [µm]
1	1.74
2	1.47
3	1.60
4	1.58
5	1.38
6	1.94
7	1.46
8	2.25
9	1.53
10	1.92
11	1.41
12	3.33
13	1.72
14	1.49
15	1.54
16	1.67

Maximum	3.33
Average	1.75

Piston Skirt to Bore Clearance, inches

	Cylinder	Average Bore Diameter	Piston Skirt Diameter	Clearance
Pre - Test	1	4.0548	4.0499	0.0049
	2	4.0548	4.0496	0.0052
	3	4.0549	4.0496	0.0053
	4	4.0549	4.0497	0.0052
	5	4.0551	4.0496	0.0054
	6	4.0550	4.0498	0.0051
	7	4.0555	4.0497	0.0058
	8	4.0555	4.0496	0.0059
Post - Test	1	4.0548	4.0497	0.0051
	2	4.0548	4.0491	0.0057
	3	4.0550	4.0489	0.0061
	4	4.0548	4.0491	0.0057
	5	4.0553	4.0490	0.0063
	6	4.0551	4.0492	0.0058
	7	4.0554	4.0495	0.0059
	8	4.0555	4.0495	0.0060

Top and Second Ring Radial Wear, inches

Top Ring				
Cylinder	Position	Before	After	Delta
1	1	0.17800	0.17730	0.00070
	2	0.18100	0.18020	0.00080
	3	0.17780	0.17695	0.00085
	4	0.17895	0.17855	0.00040
	5	0.17765	0.17725	0.00040
2	1	0.17755	0.17705	0.00050
	2	0.17875	0.17815	0.00060
	3	0.17825	0.17750	0.00075
	4	0.17860	0.17815	0.00045
	5	0.17775	0.17720	0.00055
3	1	0.17750	0.17670	0.00080
	2	0.17815	0.17755	0.00060
	3	0.17760	0.17690	0.00070
	4	0.17915	0.17840	0.00075
	5	0.17760	0.17655	0.00105
4	1	0.17905	0.17875	0.00030
	2	0.17920	0.17870	0.00050
	3	0.17700	0.17655	0.00045
	4	0.17860	0.17795	0.00065
	5	0.17880	0.17829	0.00051
5	1	0.17795	0.17550	0.00245
	2	0.17835	0.17780	0.00055
	3	0.17865	0.17805	0.00060
	4	0.17830	0.17770	0.00060
	5	0.17800	0.17740	0.00060
6	1	0.17840	0.17775	0.00065
	2	0.17775	0.17710	0.00065
	3	0.17720	0.17670	0.00050
	4	0.17915	0.17855	0.00060
	5	0.17845	0.17790	0.00055
7	1	0.17915	0.17860	0.00055
	2	0.17990	0.17915	0.00075
	3	0.17910	0.17880	0.00030
	4	0.17980	0.17940	0.00040
	5	0.17980	0.17910	0.00070
8	1	0.17800	0.17780	0.00020
	2	0.17845	0.17780	0.00065
	3	0.17740	0.17680	0.00060
	4	0.17775	0.17730	0.00045
	5	0.17820	0.17790	0.00030

Maximum	0.00245
Average	0.00062

Second Ring				
Cylinder	Position	Before	After	Delta
1	1	0.16175	0.16120	0.00055
	2	0.16145	0.16085	0.00060
	3	0.16155	0.16115	0.00040
	4	0.16180	0.16160	0.00020
	5	0.16175	0.16135	0.00040
2	1	0.16160	0.16105	0.00055
	2	0.16125	0.16075	0.00050
	3	0.16170	0.16070	0.00100
	4	0.16130	0.16080	0.00050
	5	0.16125	0.16045	0.00080
3	1	0.16165	0.16060	0.00105
	2	0.15985	0.15940	0.00045
	3	0.16130	0.15960	0.00170
	4	0.16130	0.16095	0.00035
	5	0.16130	0.16070	0.00060
4	1	0.16190	0.16135	0.00055
	2	0.16015	0.15975	0.00040
	3	0.16050	0.15975	0.00075
	4	0.16085	0.16025	0.00060
	5	0.16200	0.16130	0.00070
5	1	0.16225	0.16160	0.00065
	2	0.16240	0.16180	0.00060
	3	0.16150	0.16095	0.00055
	4	0.16115	0.16065	0.00050
	5	0.16115	0.16115	0.00000
6	1	0.16195	0.16125	0.00070
	2	0.15960	0.15915	0.00045
	3	0.16005	0.15970	0.00035
	4	0.16070	0.16035	0.00035
	5	0.16155	0.16105	0.00050
7	1	0.16130	0.16080	0.00050
	2	0.16075	0.16030	0.00045
	3	0.16105	0.16060	0.00045
	4	0.16125	0.16090	0.00035
	5	0.16160	0.16105	0.00055
8	1	0.16095	0.16015	0.00080
	2	0.15970	0.15905	0.00065
	3	0.16050	0.15980	0.00070
	4	0.16105	0.16050	0.00055
	5	0.16170	0.16115	0.00055

Maximum	0.00170
Average	0.00057

Piston Ring Gap Measurements, inches

Cylinder	Ring No.	Before	After	Delta
1	1	0.016	0.016	0.000
	2	0.038	0.038	0.000
	3	0.020	0.020	0.000
2	1	0.016	0.016	0.000
	2	0.038	0.042	0.004
	3	0.020	0.020	0.000
3	1	0.015	0.015	0.000
	2	0.039	0.042	0.003
	3	0.020	0.020	0.000
4	1	0.018	0.018	0.000
	2	0.038	0.044	0.006
	3	0.020	0.020	0.000
5	1	0.018	0.018	0.000
	2	0.038	0.039	0.001
	3	0.020	0.020	0.000
6	1	0.018	0.018	0.000
	2	0.038	0.039	0.001
	3	0.020	0.020	0.000
7	1	0.016	0.018	0.002
	2	0.038	0.045	0.007
	3	0.020	0.020	0.000
8	1	0.016	0.018	0.002
	2	0.039	0.039	0.000
	3	0.020	0.020	0.000

Ring No. 1 max increase	0.002
Ring No. 2 max increase	0.007
Ring No. 3 max increase	0.000

Ring No. 1 avg increase	0.000
Ring No. 2 avg increase	0.003
Ring No. 3 avg increase	0.000

Piston Ring Mass, grams

Cylinder	Ring No.	Before	After	Delta
1	1	22.8007	22.7239	0.0768
	2	16.9051	16.8791	0.0260
	3	15.3878	15.3724	0.0154
2	1	22.8769	22.7894	0.0875
	2	16.8187	16.7925	0.0262
	3	15.1722	15.1587	0.0135
3	1	22.8356	22.7442	0.0914
	2	16.7424	16.7177	0.0247
	3	15.0828	15.0661	0.0167
4	1	22.7842	22.6985	0.0857
	2	16.7994	16.7721	0.0273
	3	15.3211	15.3020	0.0191
5	1	22.7893	22.7107	0.0786
	2	16.8938	16.8674	0.0264
	3	15.2583	15.2393	0.0190
6	1	22.7454	22.6517	0.0937
	2	16.8075	16.7798	0.0277
	3	15.1786	15.1613	0.0173
7	1	22.9962	22.9057	0.0905
	2	16.8654	16.8418	0.0236
	3	15.1027	15.0898	0.0129
8	1	22.7955	22.7239	0.0716
	2	16.7607	16.7339	0.0268
	3	15.7580	15.1955	0.5625

Ring No. 1 max decrease	0.0937
Ring No. 2 max decrease	0.0277
Ring No. 3 max decrease	0.5625

Ring No. 1 avg decrease	0.0845
Ring No. 2 avg decrease	0.0261
Ring No. 3 avg decrease	0.0845

Connecting Rod Bearing Weight Loss, grams

Rod Bearing	Shell	Before	After	Change
1	Top	27.7789	27.7450	0.0339
	Bottom	27.7795	27.7448	0.0347
2	Top	27.8320	27.8173	0.0147
	Bottom	27.8553	27.8376	0.0177
3	Top	27.7987	27.7748	0.0239
	Bottom	27.8008	27.7718	0.0290
4	Top	27.8565	27.8134	0.0431
	Bottom	27.8947	27.8252	0.0695
5	Top	27.7975	27.7817	0.0158
	Bottom	27.7802	27.7647	0.0155
6	Top	27.9424	27.8970	0.0454
	Bottom	27.9198	27.8495	0.0703
7	Top	28.0086	27.9422	0.0664
	Bottom	27.9163	27.8599	0.0564
8	Top	28.0248	27.9832	0.0416
	Bottom	27.9677	27.9135	0.0542

Maximum	0.0703
Average	0.0395

Main Bearing Weight Loss, grams

Main Bearing	Shell	Before	After	Change
1	Top	48.5483	48.5226	0.0257
	Bottom	52.6478	52.6241	0.0237
2	Top	48.5894	48.5654	0.0240
	Bottom	52.5165	52.4827	0.0338
3	Top	93.8623	93.6966	0.1657
	Bottom	99.8403	99.4058	0.4345
4	Top	48.8270	48.7977	0.0293
	Bottom	52.4111	52.3806	0.0305
5	Top	68.9364	68.8953	0.0411
	Bottom	73.3157	73.2327	0.0830

Maximum	0.4345
Average	0.0891

Stanadyne Pump Calibration / Evaluation

Pump Type : DB2831-5079 (arctic)	**SN: 14653942**
Test condition :	**AL:**

PUMP RPM	*Description*	*Spec.*	*Before*	*After*	*Change*
1000	Transfer pump psi.	60-62 psi	62	62	0
	Return Fuel	225-375 cc	306	340	34
350	Low Idle	12-16 cc	14	16	2
	Housing psi.	8-12 psi	8	11	3
	Advance	3.5 deg. min	5.43	3.5	1.93
	Cold Advance Solenoid	0-1 psi.	0.5	0.5	0
750	Shut-Off	4 cc max.	0.5	0	0.5
900	Fuel Delivery	66.5 - 69.5cc	68.5	67	1.5
1600	WOT Fuel delivery	59.5 min.	64	63	1
	WOT Advance	2.5 - 3.5 deg.	3.43	1.97	1.46
	Face Cam Fuel delivery	21.5 - 23.5	22	22	0
	Face Cam Advance	5.25 - 7.25 deg.	6.79	5.57	1.22
	Low Idle	11 - 12 deg.	11	9.54	1.46
1825	Fuel Delivery	33 cc min.	37	53	16
1950	High Idle	15 cc max.	0.5	3	2.5
	Transfer pump psi.	125 psi max.	108	109	1
200	WOT Fuel Delivery	58 cc min.	60.5	62	1.5
	WOT Shut-Off	4 cc max.	0.5	0.5	0
75	Low Idle Fuel Delivery	37 cc min.	52	52	0
	Transfer pump psi.	16 psi min.	25	30	5
	Housing psi.	0 -12 psi	2	3	1
	Air Timing	-.5 deg.(+/-.5 deg)	-0.5	-0.5	0
	Fluid Temp. Deg. C				
	Date				

*Pump calibration data to be used for reference only

Photographs

GEP 6.5 - Wheeled Vehicle Cycle

Oil Code:	LO-251746	**EOT Date:**	7/9/10
Test No.:	LO251746-65T1-W-210	**Test Length:**	168

Piston Skirt Thrust - Best Cyl 2

Piston Skirt Anti-thrust - Best Cyl 2

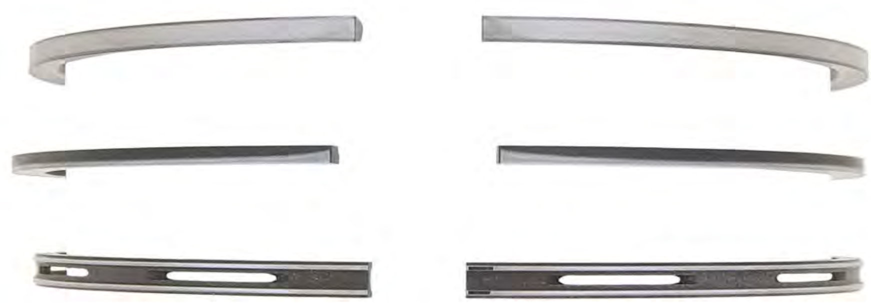
Oil Code:	LO-251746	**EOT Date:**	7/9/10
Test No.:	LO251746-65T1-W-210	**Test Length:**	168

Piston Skirt Thrust - Worst Cyl 7

Piston Skirt Anti-thrust - Worst Cyl 7

Oil Code:	LO-251746	**EOT Date:**	7/9/10
Test No.:	LO251746-65T1-W-210	**Test Length:**	168

Piston Rings - Best Cyl 1



Piston Rings - Worst Cyl 8

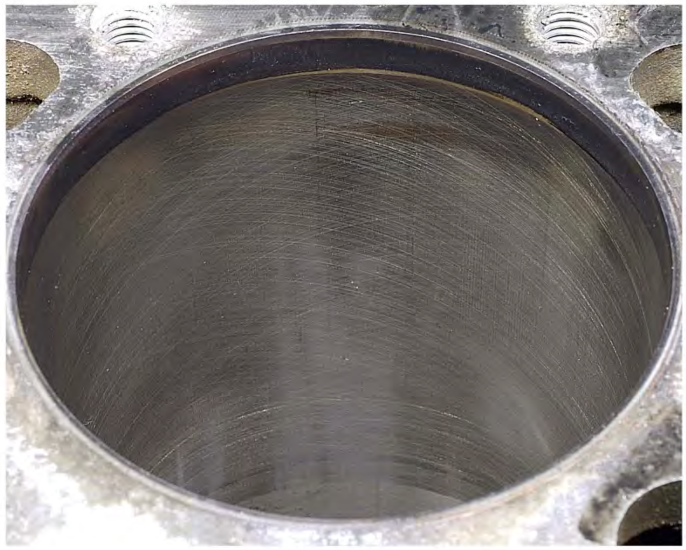
Oil Code:	LO-251746	EOT Date:	7/9/10
Test No.:	LO251746-65T1-W-210	Test Length:	168

Piston Undercrown - Best Cyl 2

Piston Undercrown - Worst Cyl 7

Oil Code:	LO-251746	EOT Date:	7/9/10
Test No.:	LO251746-65T1-W-210	Test Length:	168

Engine Block Cylinder Bore - Best Cyl 4



Engine Block Cylinder Bore - Worst Cyl 3

Oil Code:	LO-251746	**EOT Date:**	7/9/10
Test No.:	LO251746-65T1-W-210	**Test Length:**	168

Exhaust and Intake Valve - Best Cyl 4

Oil Code:	LO-251746	**EOT Date:**	7/9/10
Test No.:	LO251746-65T1-W-210	**Test Length:**	168

Exhaust and Intake Valve - Worst Cyl 7

Oil Code:	LO-251746	EOT Date:	7/9/10
Test No.:	LO251746-65T1-W-210	Test Length:	168

Rod Bearings

Oil Code:	LO-251746	EOT Date:	7/9/10
Test No.:	LO251746-65T1-W-210	Test Length:	168

Main Bearings

APPENDIX D1. – EVAULATION OF CANDIDATE LO253071 IN ALLISON C4 TRANSMISSION TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID,
TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted For

SWRI ARMY LAB

Oil Code:
LO253071

Test Number:
C4-8-1286

July 22, 2010

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

VIII. Graphite Clutch Friction Test

Test Laboratory: SWRI
Test Number: C4-8-1286
Friction Plate Batch: BATCH 44
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-253071
Sponsor Fluid Code: LO253071
Completion Date: 7/22/2010

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0650	0.0580

	Before	After
Pack Clearance	0.4572	0.6604

Reference Tests

Test Number	Test Date	Test Fluid
C4-0-1257	11/25/09	PASS REF-L-06-04
C4-0-1267	01/08/10	PASS REF-L-06-04
C4-0-1278	05/26/10	PASS REF-L-06-04

	New	EOT
Viscosity at 40°C, cSt	43.73	36.56
Viscosity at 100°C, cSt	8.39	7.14
Iron Content, ppm	2	49

D5185	New Fluid (ppm)
Ba	<1
B	<1
Ca	3518
Mg	11
P	1261
Si	6
Na	18
Zn	1838

Name: Matt Jackson

Signature:

Title: Manager

Date: 7/30/10

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO253071**	Test Number: **C4-8-1286**
Lab Fluid Code: **LO-253071**	Fric. Plate Batch: **BATCH 44**
Completion Date: **7/22/2010**	Steel Plate Batch: **10/9/2008**

PHASE A

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
500	1.19	49	62	43	19	75	60
1000	1.25	47	62	41	21	70	61

PHASE B

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (0.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
1500	0.79	99	138	90	48	164	139
2000	0.84	92	135	79	56	166	139
2500	0.87	90	135	75	60	159	137
3500	0.88	89	132	69	63	146	135
4000	0.89	88	130	69	61	152	135
4500	0.90	88	128	68	60	153	134
5000	0.89	90	127	67	60	153	133
5500	0.91	88	120	67	53	145	131

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.79	0.91	15.19	F
0.2 Second Dynamic Coeff.	N/A	N/A	0.084	0.063	-25.000	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.093	0.082	-11.828	F
Static Friction Coeff.	N/A	N/A	0.129	0.112	-13.178	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.154	0.136	-11.688	
0.25 Second Low Speed Coeff.	N/A	N/A	0.130	0.123	-5.385	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-GRAPHITE FRICTION TEST

Candidate Fluid: LO253071 | **Test Number : C4-8-1286** | **Completion Date : 7/22/2010**

Lab Fluid Code : LO253071 | **Steel Plate Batch: 10/09/2008** | **Fric Plate Batch : LOT 44**

(all units in mm)

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.2490	2.1870	2.2470	2.1990	0.0620		0.0480
	120	2.2530	2.1880	2.2580	2.1940	0.0650		0.0640
	240	2.2530	2.1920	2.2500	2.2020	0.0610		0.0480
	Average					0.0627	0.0580	0.0533
STEEL SEPARATORS								
1	Top	1.7620	1.7620	1.7620	1.7620	0.0000		0.0000
	120	1.7650	1.7650	1.7650	1.7650	0.0000		0.0000
	240	1.7670	1.7670	1.7650	1.7650	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7660	1.7660	1.7680	1.7680	0.0000		0.0000
	120	1.7660	1.7660	1.7650	1.7650	0.0000		0.0000
	240	1.7660	1.7660	1.7660	1.7660	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T.: PLATES IN GOOD CONDITION

(Anything Unusual)

Test Date: 7/22/2010

Operator's Name: JOE M

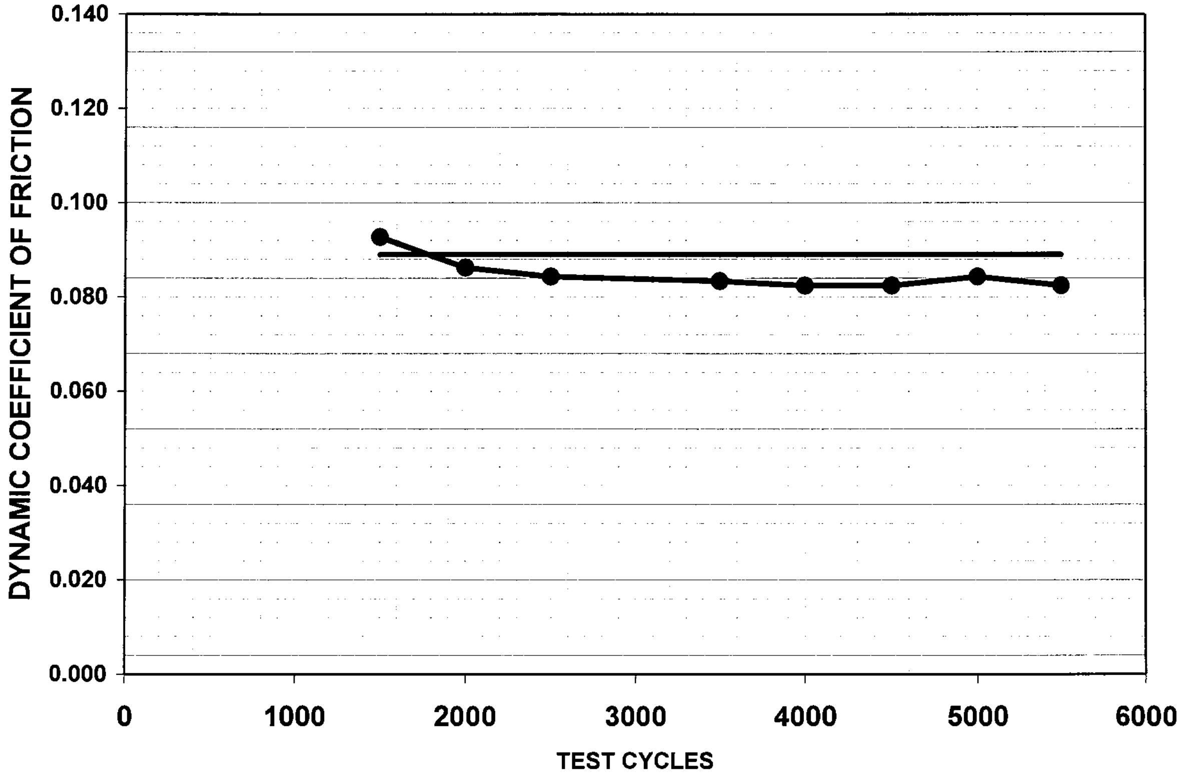
Reviewed By (Signature and Date)

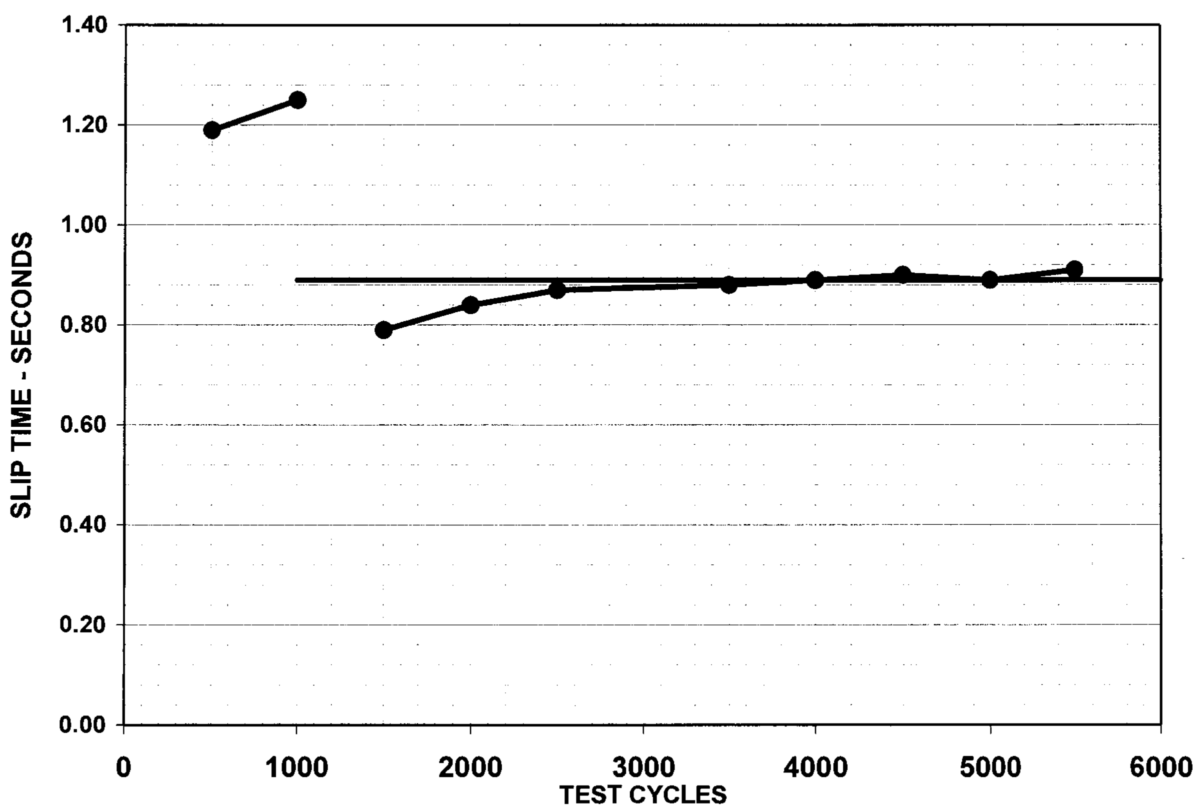
7/30/10

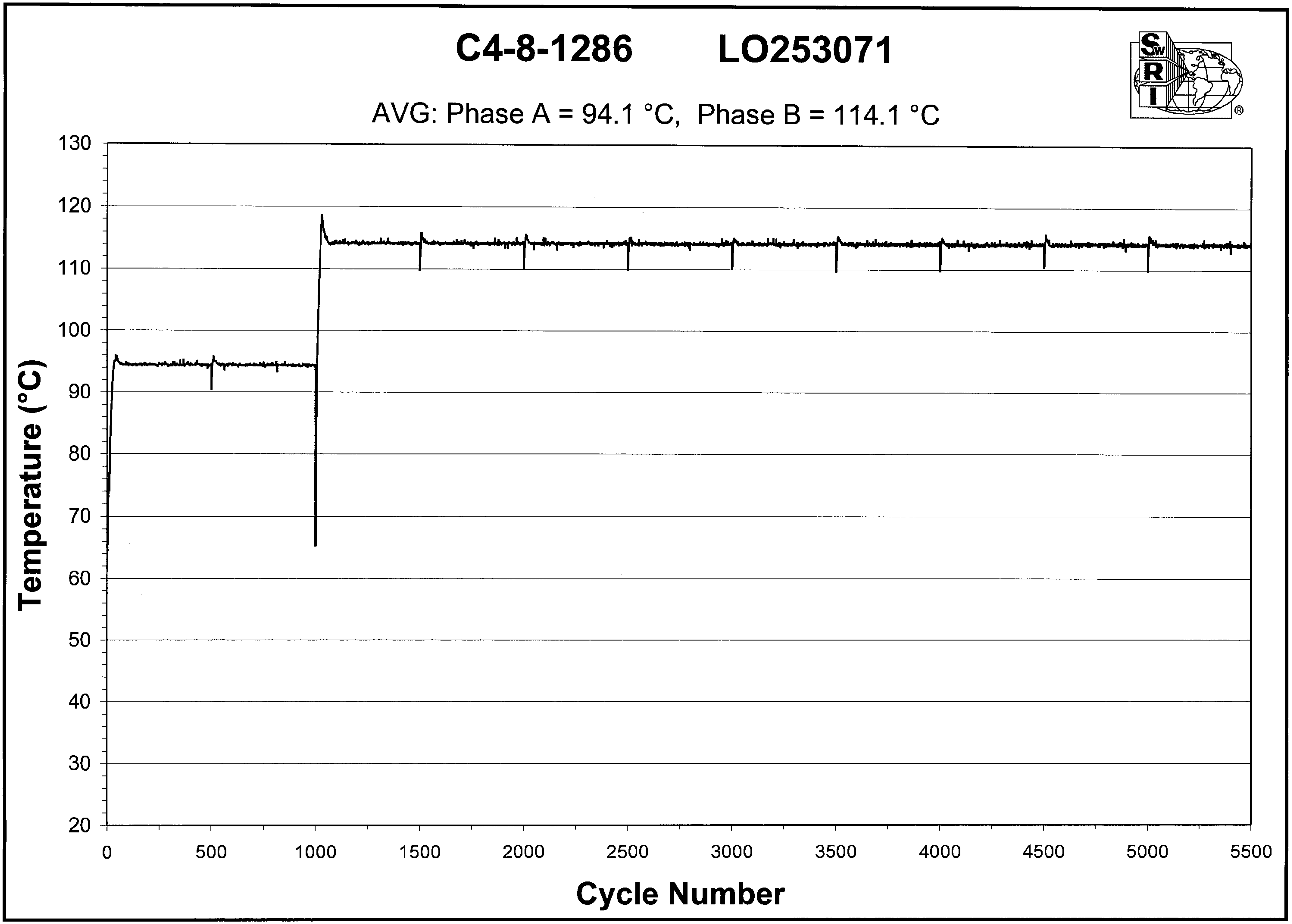
Pack ID#: 4420

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST

EOT Date: 7/22/2010 Fluid Code: LO253071
Test Number: C4-8-1286 Plate Batch: BATCH 44
Steel Batch: 10/9/2008



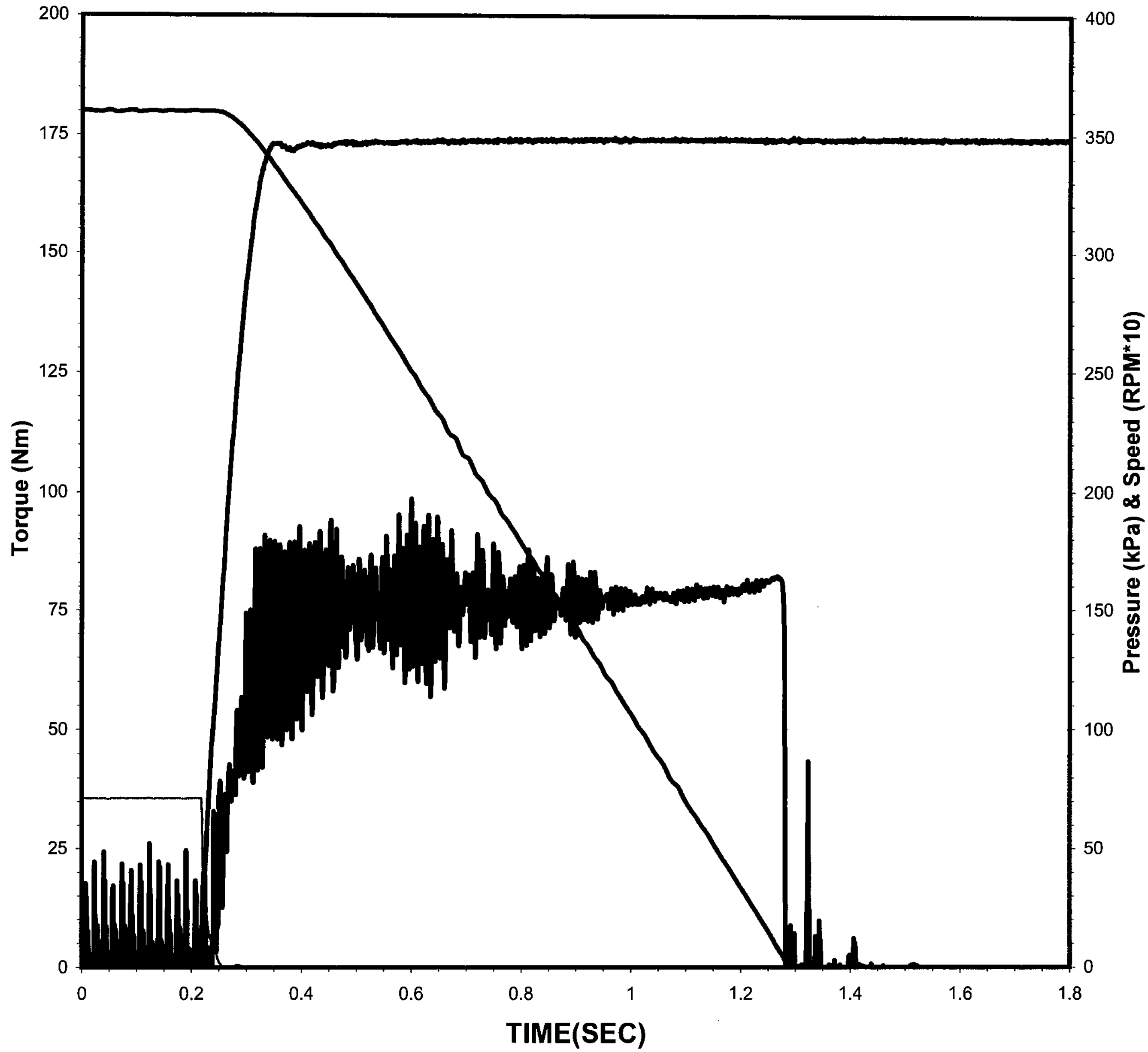



C4-8-1286 LO253071
AVG: Phase A = 94.1 °C, Phase B = 114.1 °C
Temperature (°C)
130
120
110
100
90
80
70
60
50
40
30
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Cycle Number

DYNAMIC TRACES

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/21/2010
Time of Test:	13:24:08
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	10
Temperature:	77.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	348 kPa (345 ± 7 KPa)
Apply Rate:	0.12 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.063 Sec

Torque

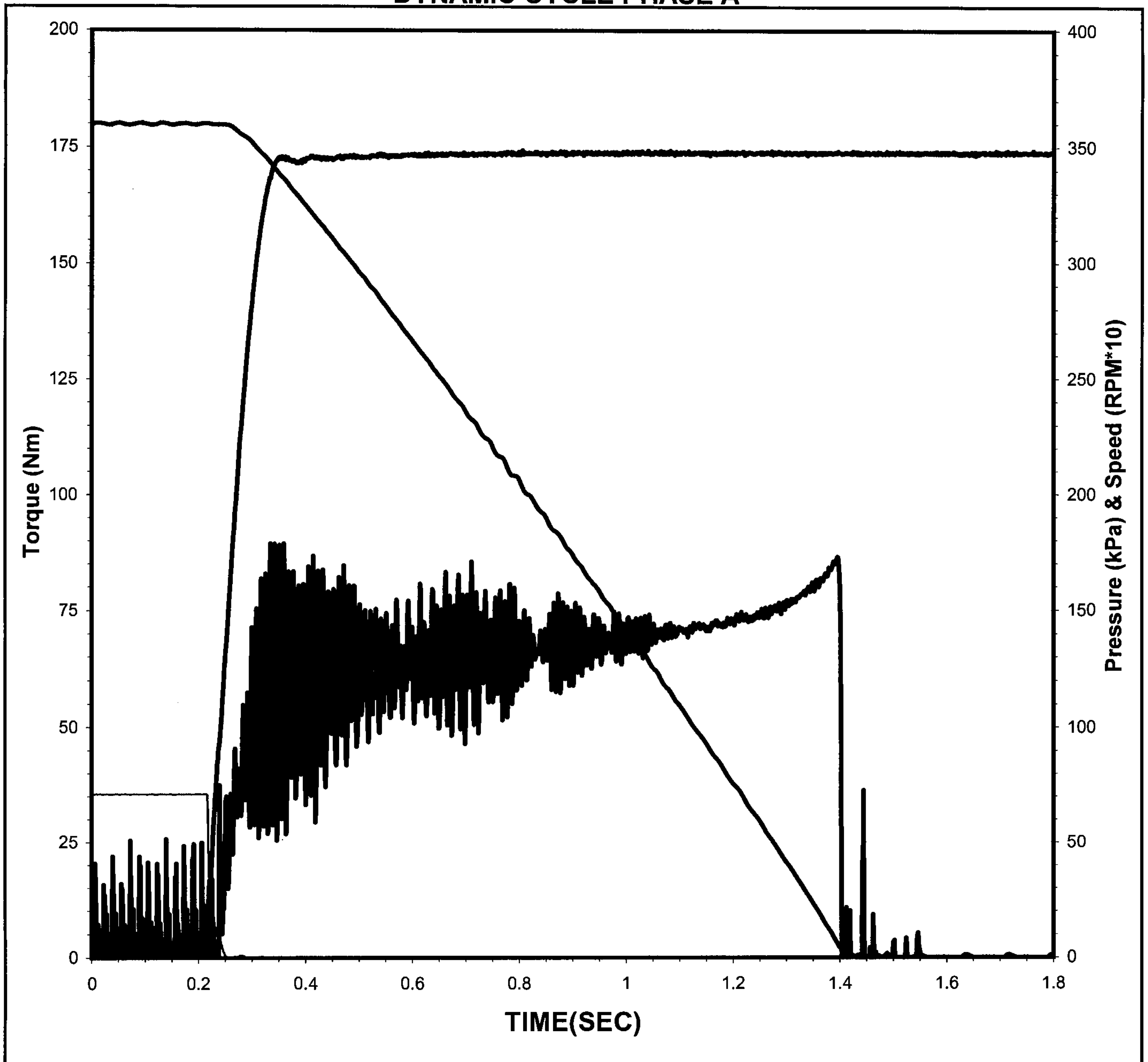
0.2 Sec Dyn:	74 N*m
Midpoint Dyn:	77 N*m
LwSpd Dynamic:	79 N*m

Coefficient of Friction

.2 Sec Dyn:	0.122
Midpoint Dyn:	0.129
LwSpd Dynamic:	0.132

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/21/2010

Time of Test: 15:26:35

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 499

Temperature: 94.5 °C
(93.3 ± 3.0 °C)

Apply Pressure: 349 kPa
(345 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 14.2 KJ
(14.50 ± 0.40 KJ)

Engage Time: 1.186 Sec

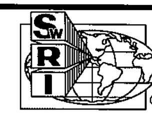
Torque

0.2 Sec Dyn:	62 N*m
Midpoint Dyn:	67 N*m
LwSpd Dynamic:	83 N*m

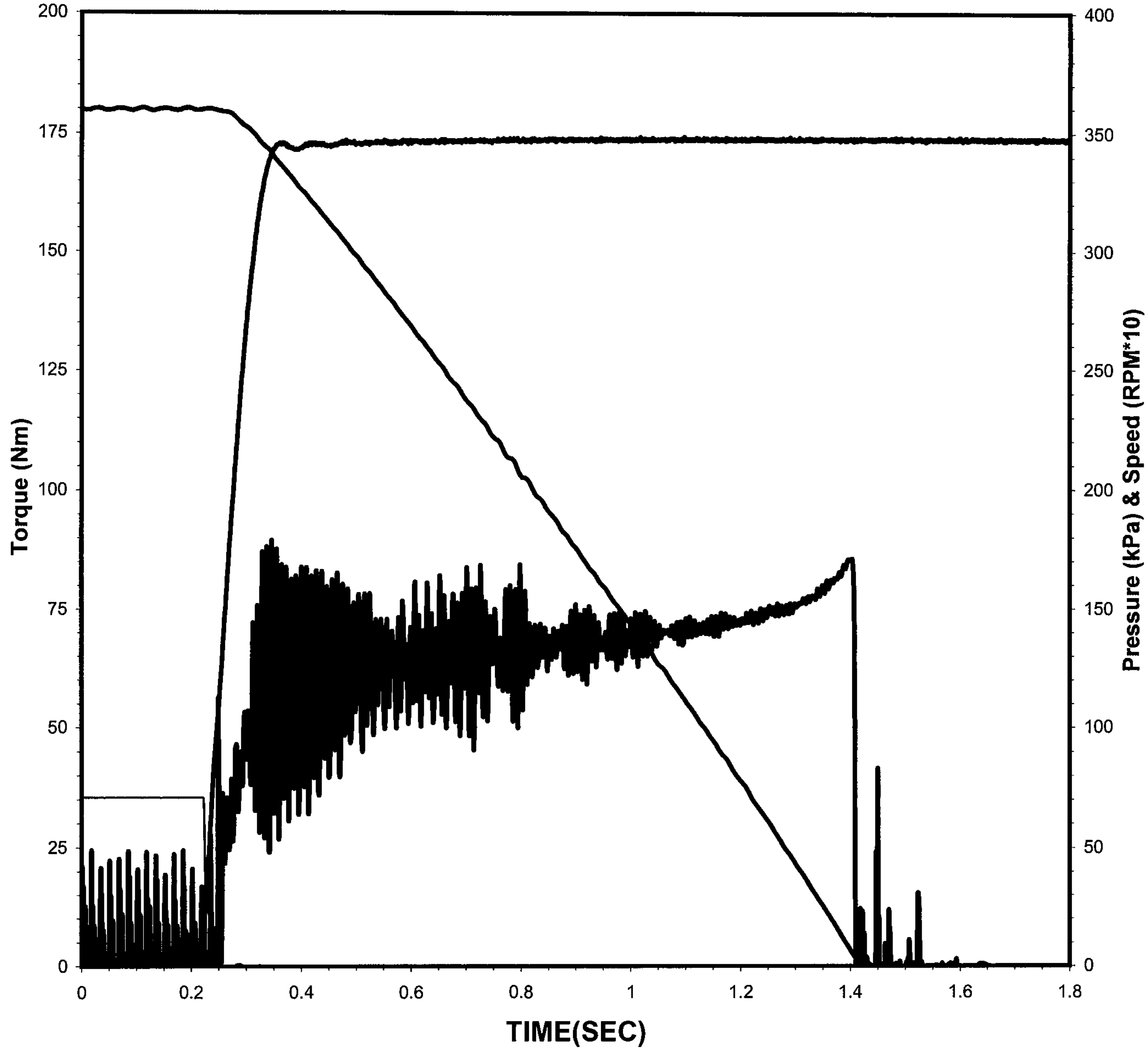
Coefficient of Friction

.2 Sec Dyn:	0.102
Midpoint Dyn:	0.112
LwSpd Dynamic:	0.138

ALLISON C-4 GRAPHITE DATA



DYNAMIC CYCLE PHASE A



Date of Test:	7/21/2010
Time of Test:	15:26:50
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	500
Temperature:	94.2 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	349 kPa
	(345 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	14.2 KJ
	(14.50 ± 0.40 KJ)
Engage Time:	1.186 Sec

Torque

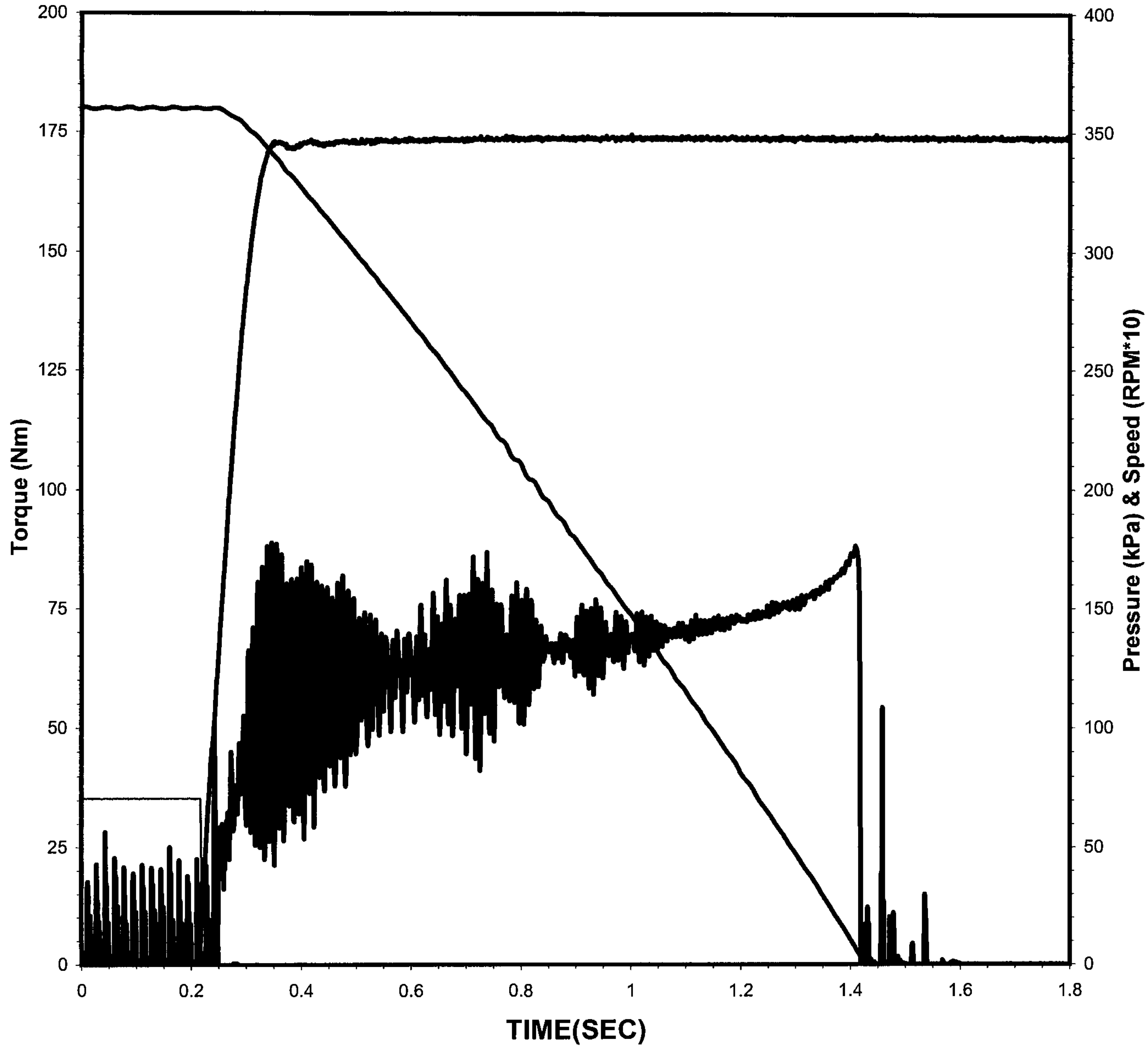
0.2 Sec Dyn:	61 N*m
Midpoint Dyn:	67 N*m
LwSpd Dynamic:	84 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.112
LwSpd Dynamic:	0.139

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/21/2010

Time of Test: 15:27:17

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 501

Temperature: 90.3 °C
(93.3 ± 3.0 °C)

Apply Pressure: 349 kPa
(345 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 14.2 KJ
(14.50 ± 0.40 KJ)

Engage Time: 1.201 Sec

Torque

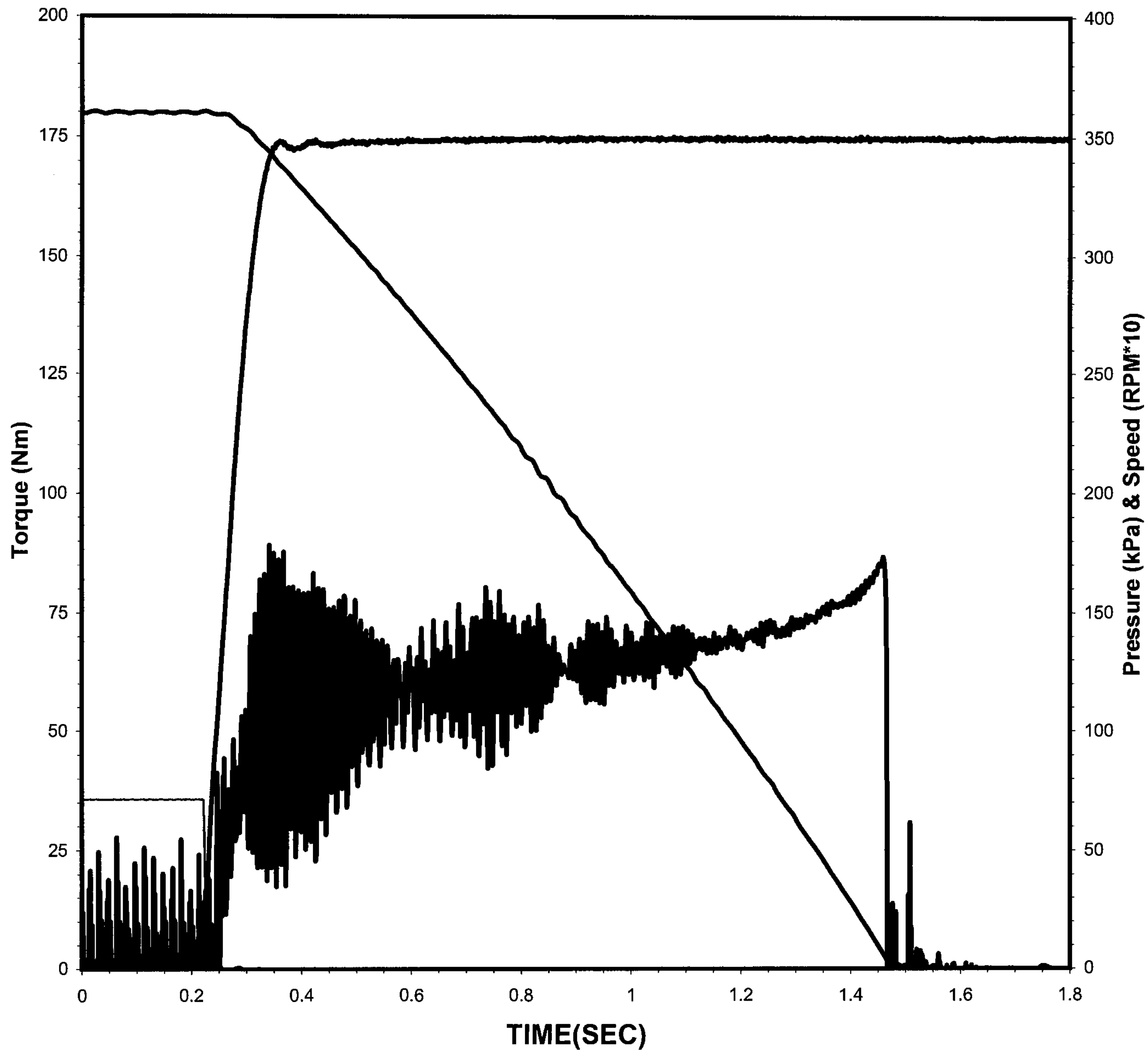
0.2 Sec Dyn:	56 N*m
Midpoint Dyn:	66 N*m
LwSpd Dynamic:	84 N*m

Coefficient of Friction

.2 Sec Dyn:	0.093
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.140

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/21/2010

Time of Test: 17:31:32

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 998

Temperature: 94.4 °C
(93.3 ± 3.0 °C)
Apply Pressure: 350 kPa
(345 ± 7 KPa)
Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)
Energy: 14.2 KJ
(14.50 ± 0.40 KJ)
Engage Time: 1.244 Sec

Torque

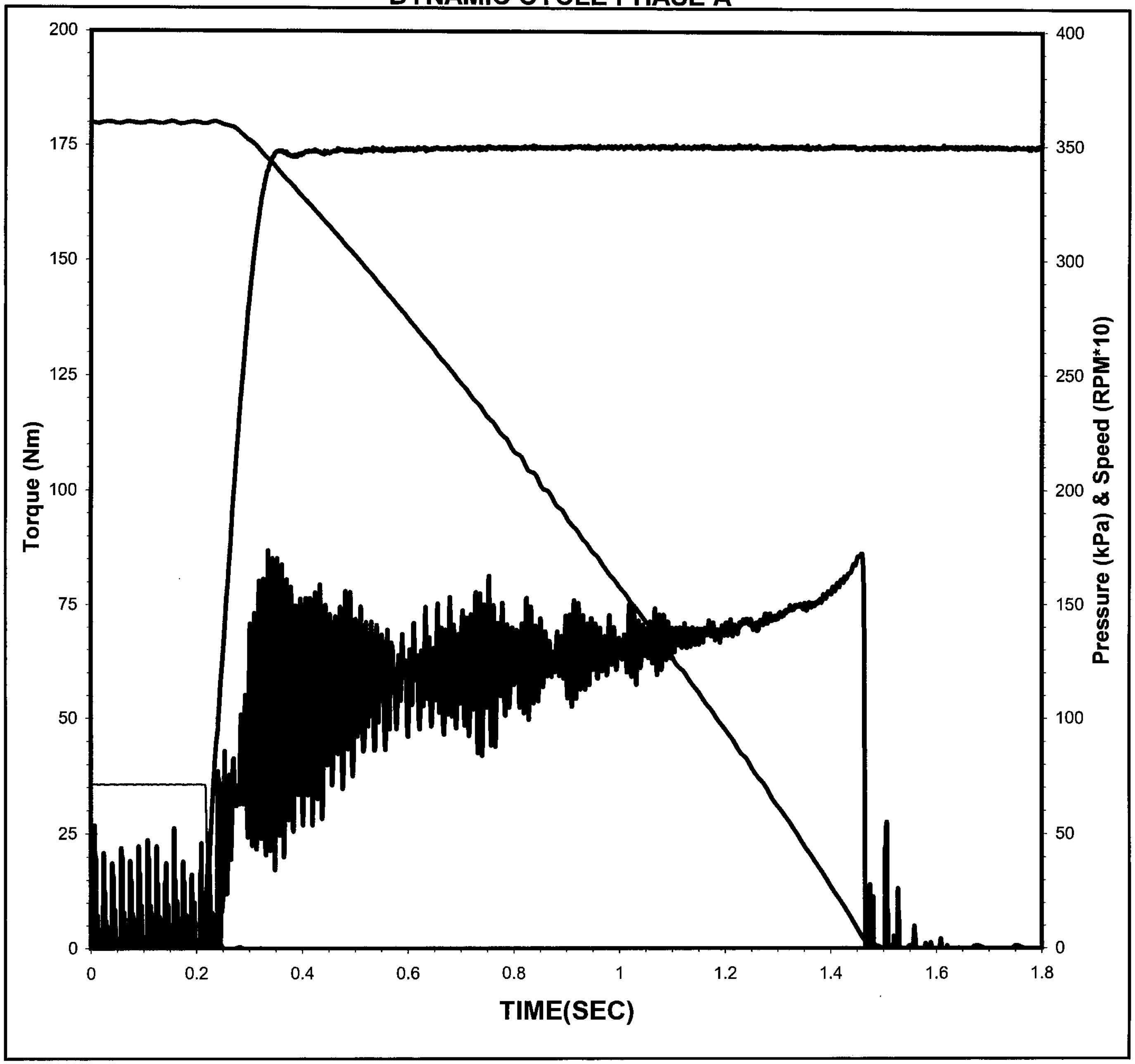
0.2 Sec Dyn: 54 N*m
Midpoint Dyn: 64 N*m
LwSpd Dynamic: 83 N*m

Coefficient of Friction

.2 Sec Dyn: 0.090
Midpoint Dyn: 0.106
LwSpd Dynamic: 0.138

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/21/2010

Time of Test: 17:31:47

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 999

Temperature: 94.5 °C
(93.3 ± 3.0 °C)

Apply Pressure: 350 kPa
(345 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 14.3 KJ
(14.50 ± 0.40 KJ)

Engage Time: 1.247 Sec

Torque

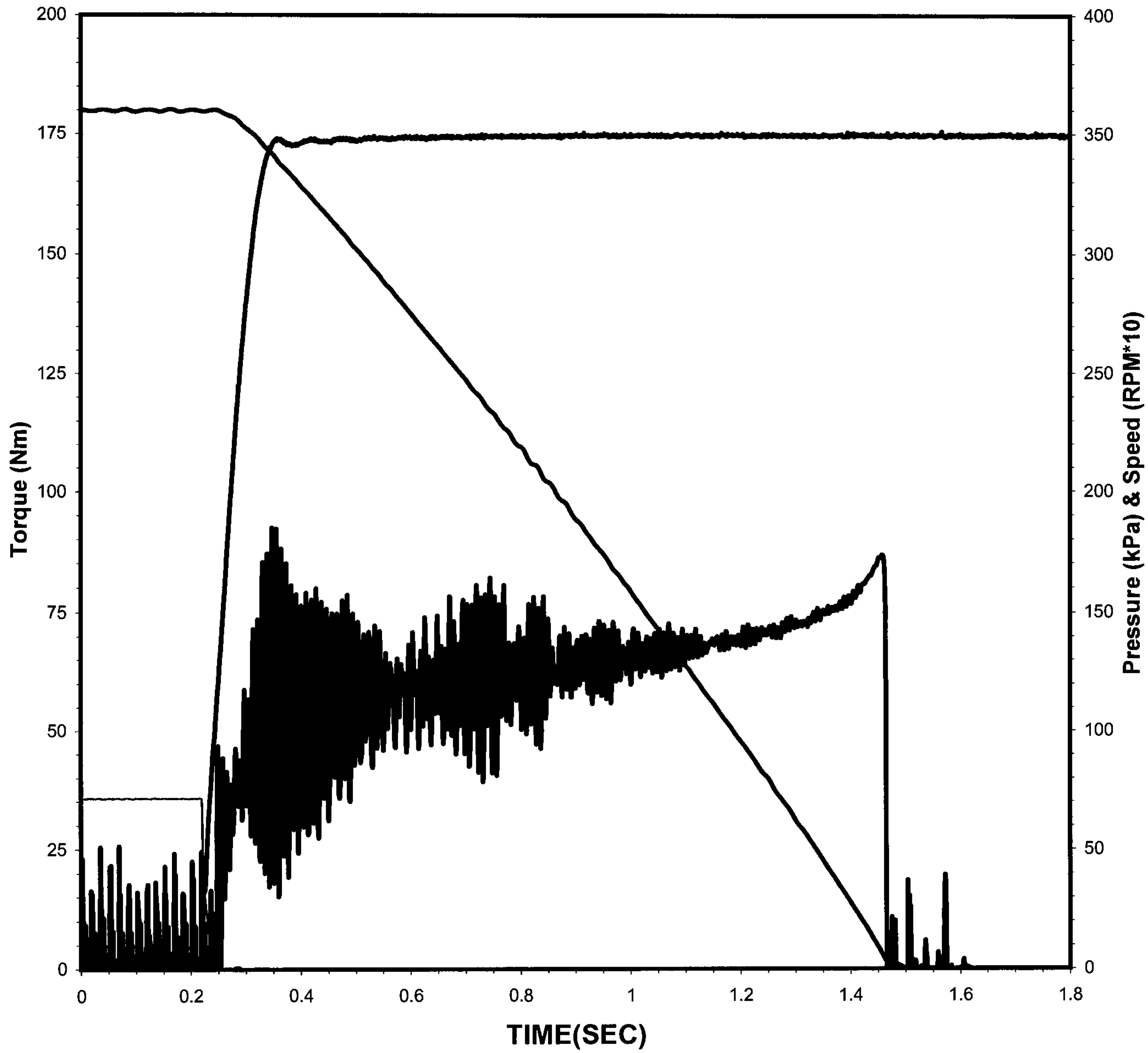
0.2 Sec Dyn:	56 N*m
Midpoint Dyn:	64 N*m
LwSpd Dynamic:	85 N*m

Coefficient of Friction

.2 Sec Dyn:	0.093
Midpoint Dyn:	0.106
LwSpd Dynamic:	0.140

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	**7/21/2010**
Time of Test:	**17:32:02**
Test Number:	**C4-8-1286**
Fluid Code:	**LO253071**
Cycle Number:	**1000**
Temperature:	**94.5 °C**
	(93.3 ± 3.0 °C)
Apply Pressure:	**350 kPa**
	(345 ± 7 KPa)
Apply Rate:	**0.12 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**14.2 KJ**
	(14.50 ± 0.40 KJ)
Engage Time:	**1.245 Sec**

Torque

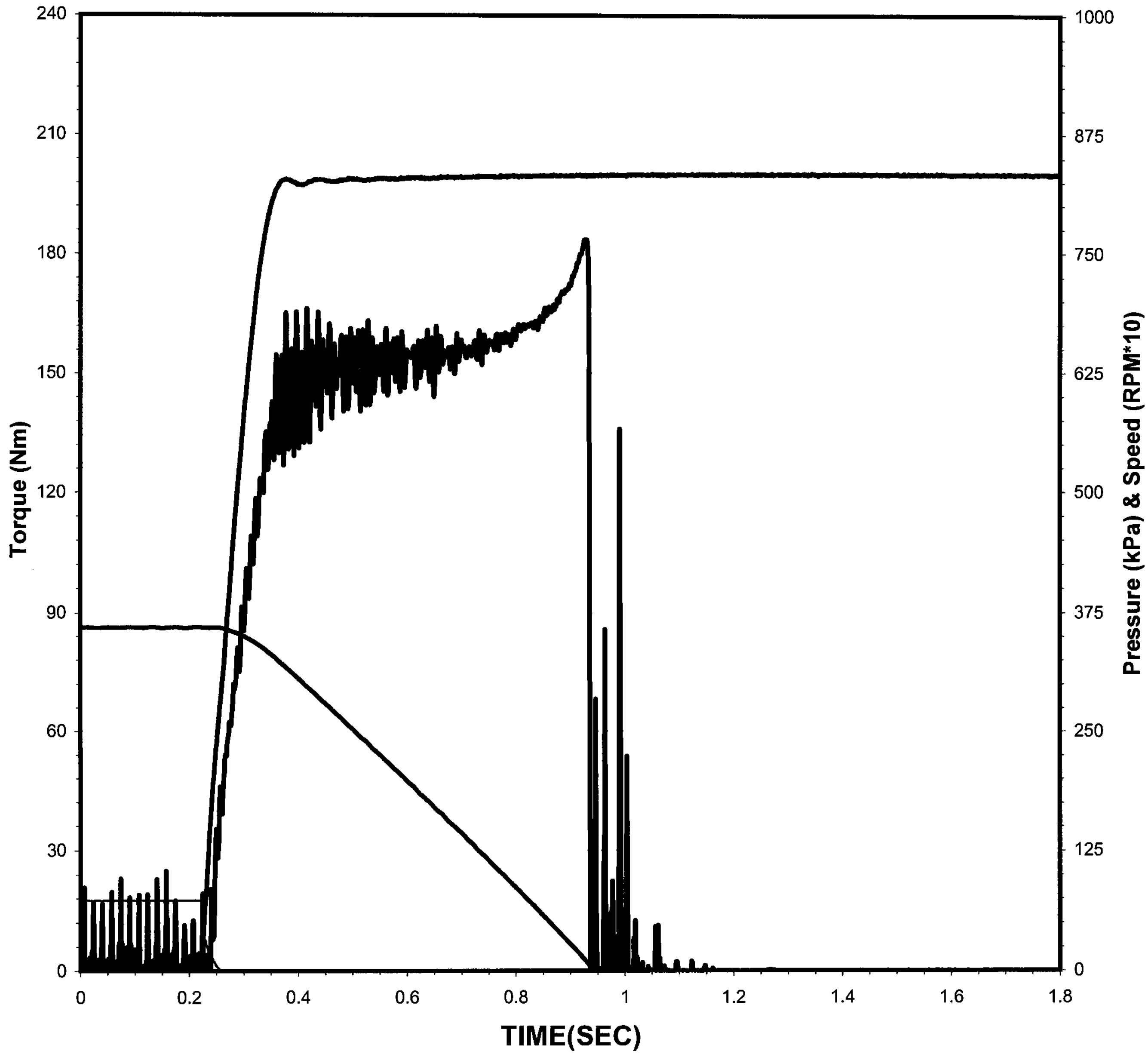
0.2 Sec Dyn:	**56 N*m**
Midpoint Dyn:	**64 N*m**
LwSpd Dynamic:	**84 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.093**
Midpoint Dyn:	**0.106**
LwSpd Dynamic:	**0.139**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	17:50:52
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	1010
Temperature:	97.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.15 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.713 Sec

Torque

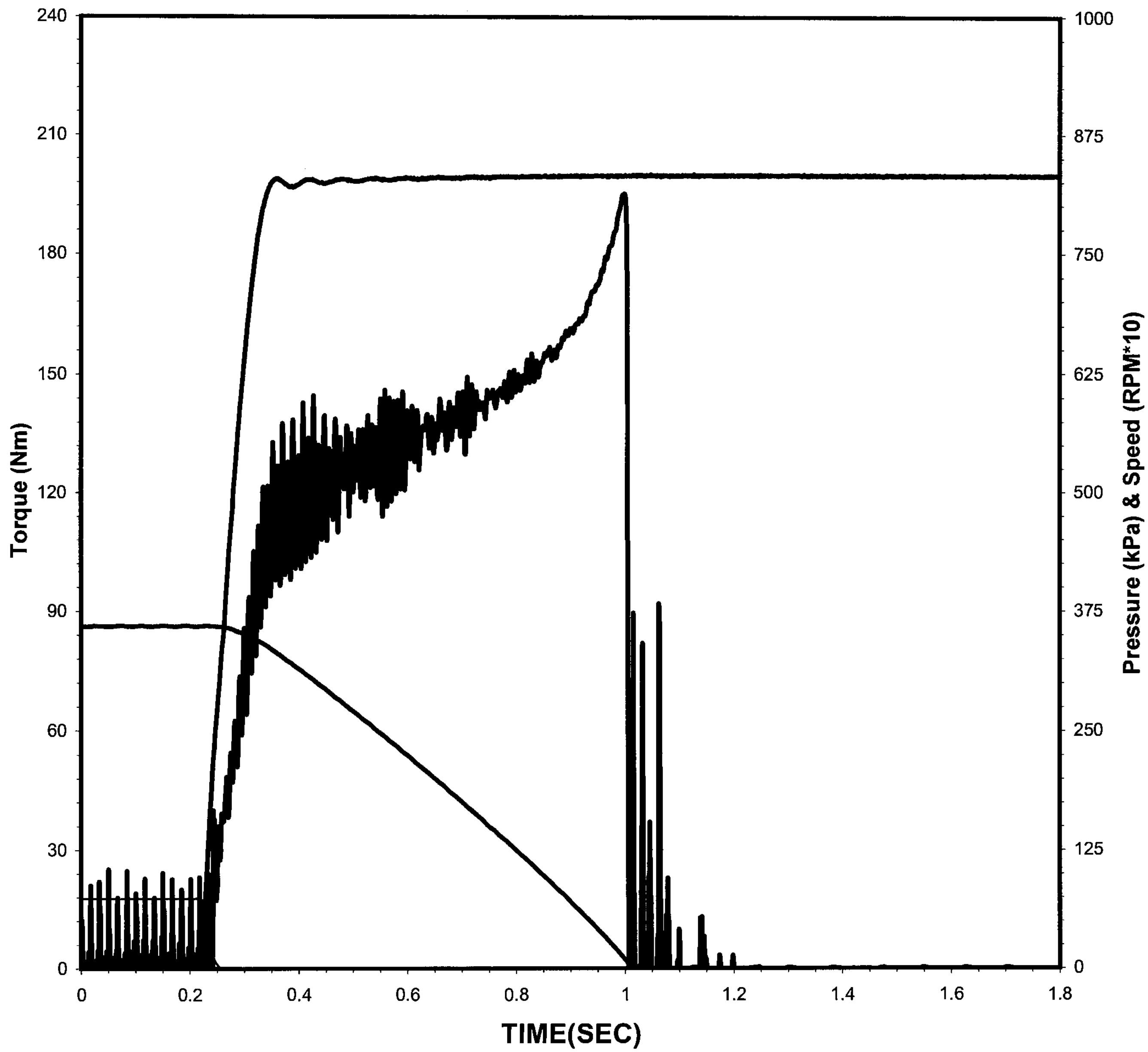
0.2 Sec Dyn:	148 N*m
Midpoint Dyn:	154 N*m
LwSpd Dynamic:	180 N*m

Coefficient of Friction

.2 Sec Dyn:	0.102
Midpoint Dyn:	0.106
LwSpd Dynamic:	0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 19:53:07

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 1499

Temperature: 114.2 °C
(112.7 ± 3.0 °C)

Apply Pressure: 830 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.783 Sec

Torque

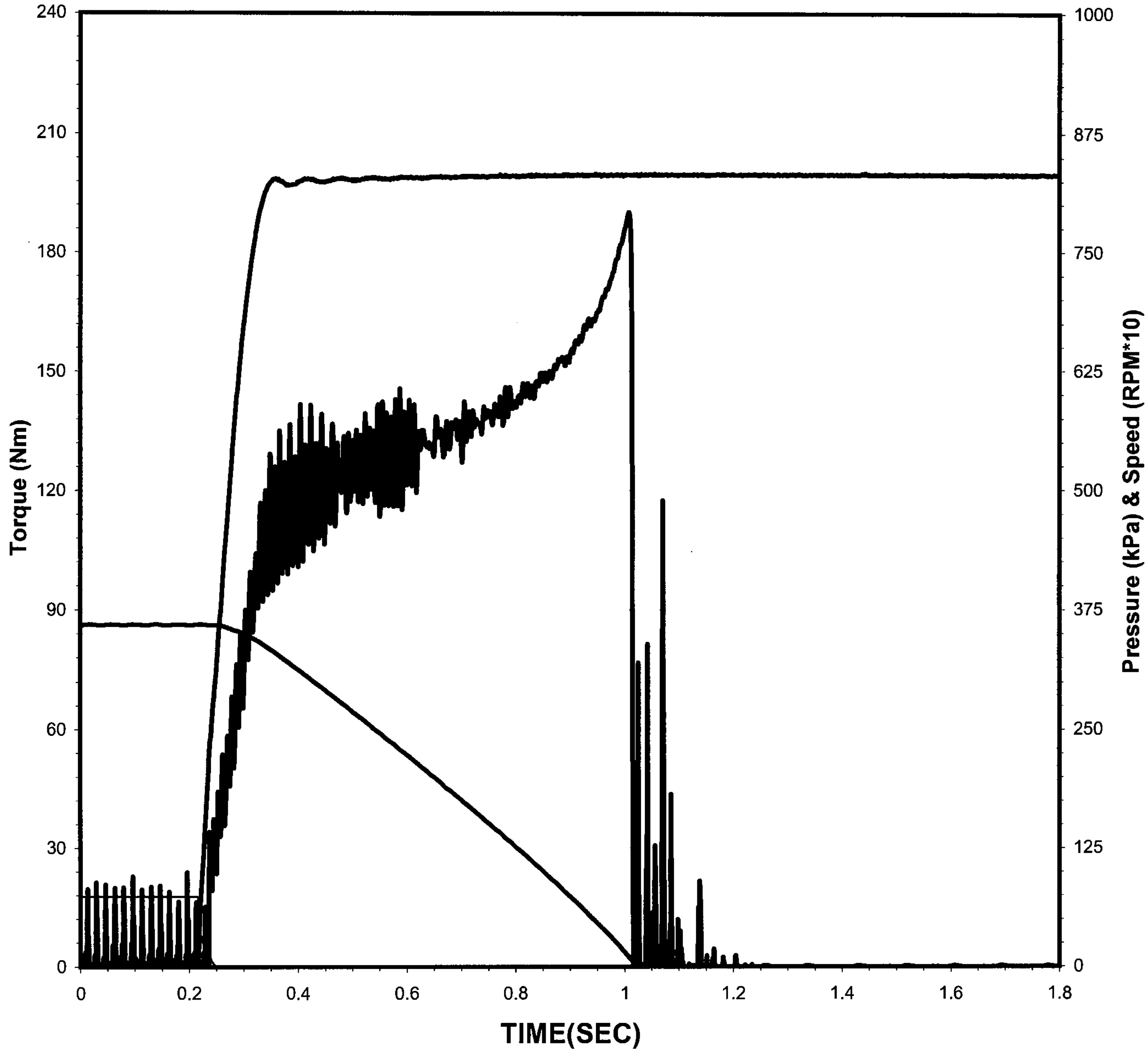
0.2 Sec Dyn:	124 N*m
Midpoint Dyn:	135 N*m
LwSpd Dynamic:	189 N*m

Coefficient of Friction

.2 Sec Dyn:	0.086
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.130

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	19:53:22
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	1500
Temperature:	113.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.799 Sec

Torque

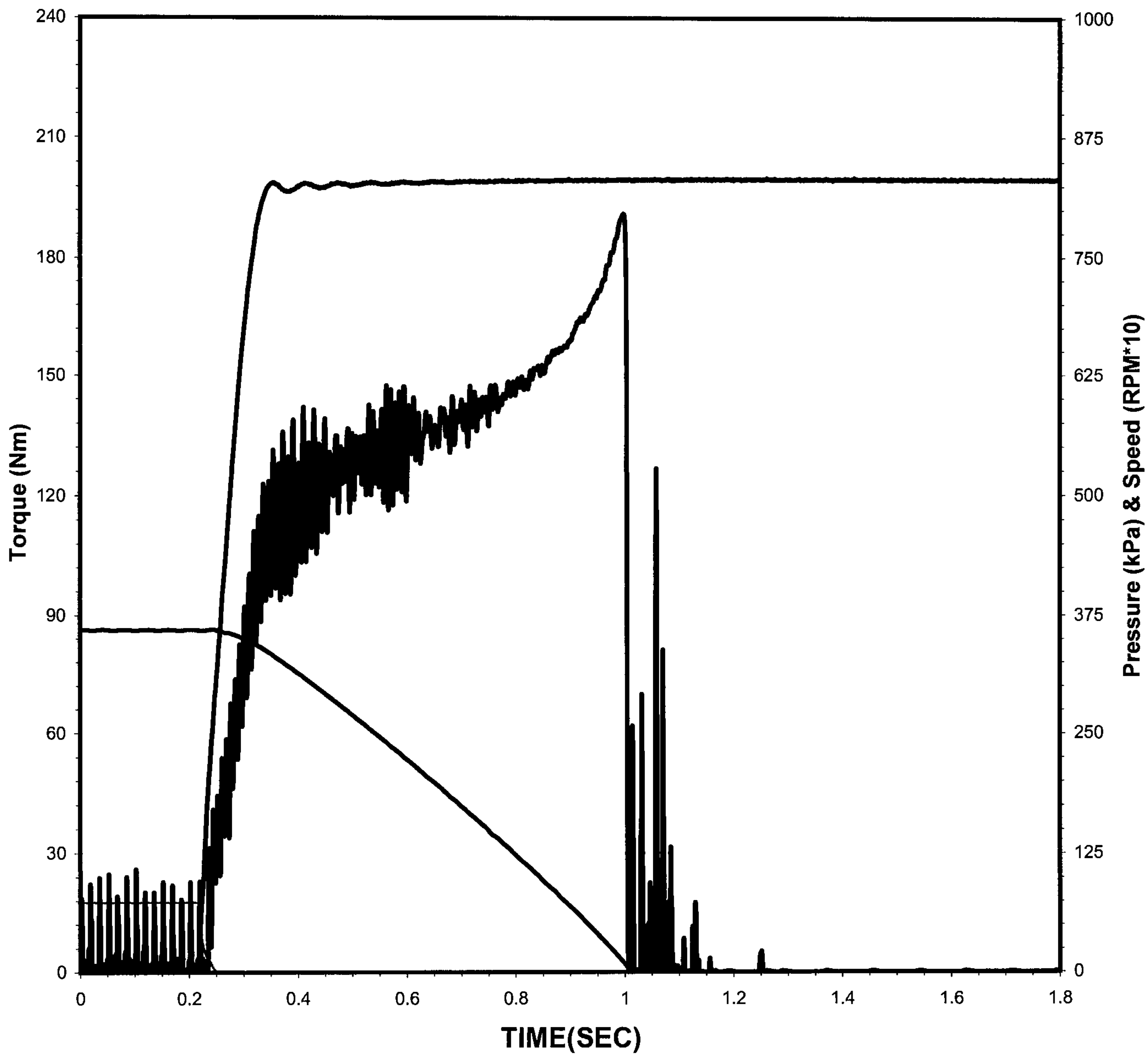
0.2 Sec Dyn:	124 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	187 N*m

Coefficient of Friction

.2 Sec Dyn:	0.085
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.129

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	19:53:49
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	1501
Temperature:	109.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.788 Sec

Torque

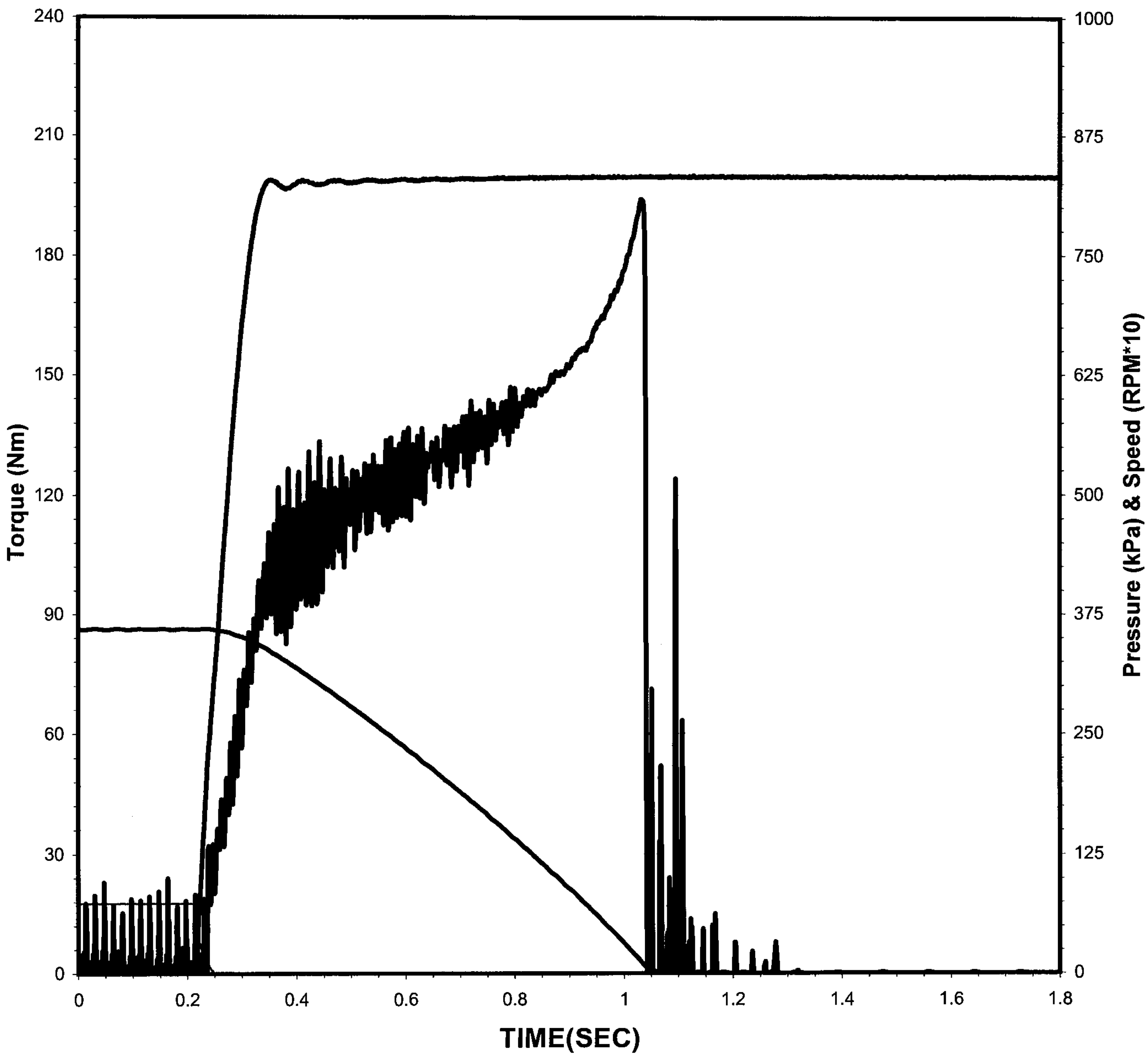
0.2 Sec Dyn:	120 N*m
Midpoint Dyn:	135 N*m
LwSpd Dynamic:	185 N*m

Coefficient of Friction

.2 Sec Dyn:	0.083
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	21:58:19
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	1999
Temperature:	114.3 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.825 Sec

Torque

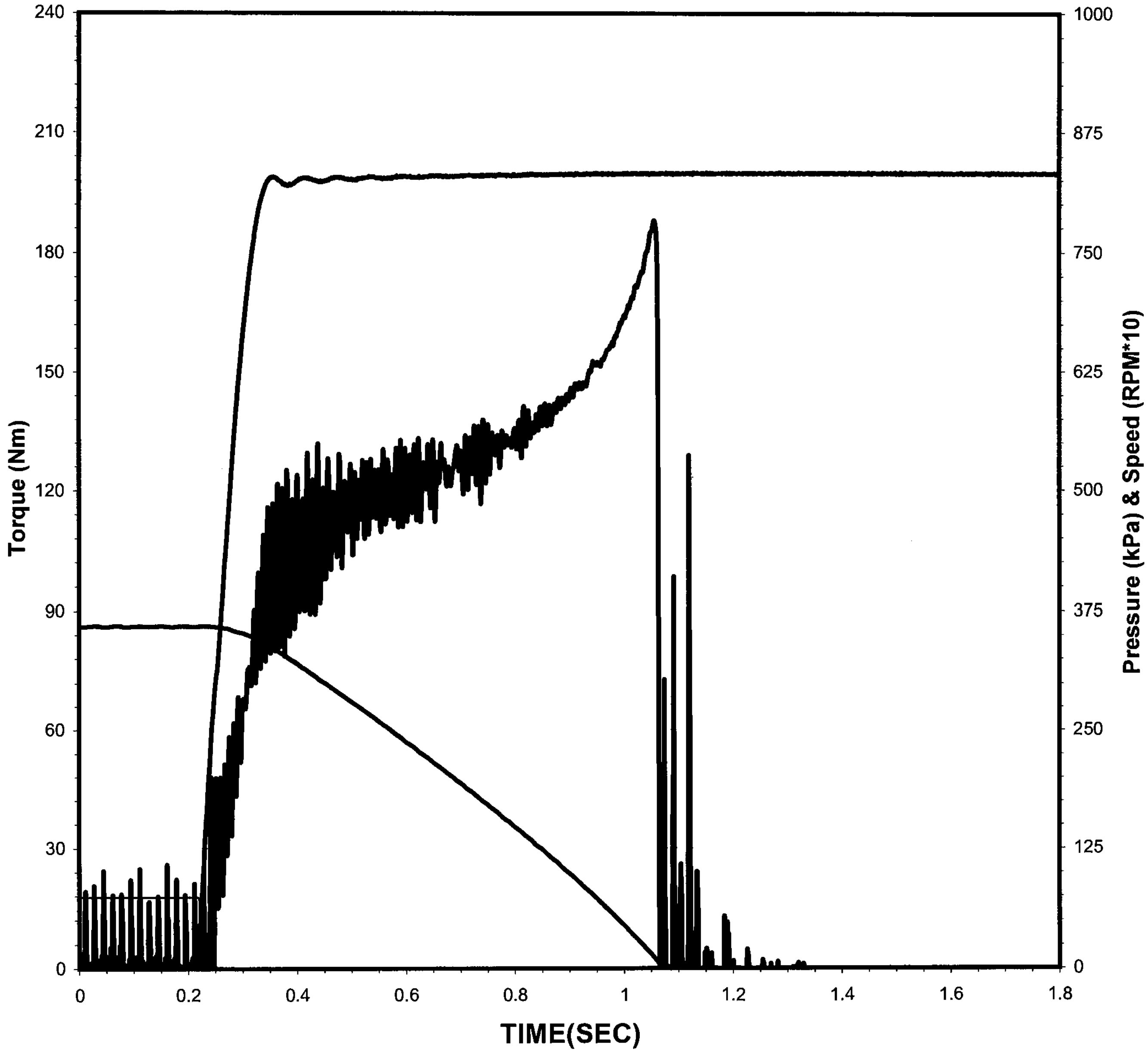
0.2 Sec Dyn:	112 N*m
Midpoint Dyn:	128 N*m
LwSpd Dynamic:	191 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.132

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 21:58:34

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 2000

Temperature: 114.0 °C
(112.7 ± 3.0 °C)

Apply Pressure: 830 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.845 Sec

Torque

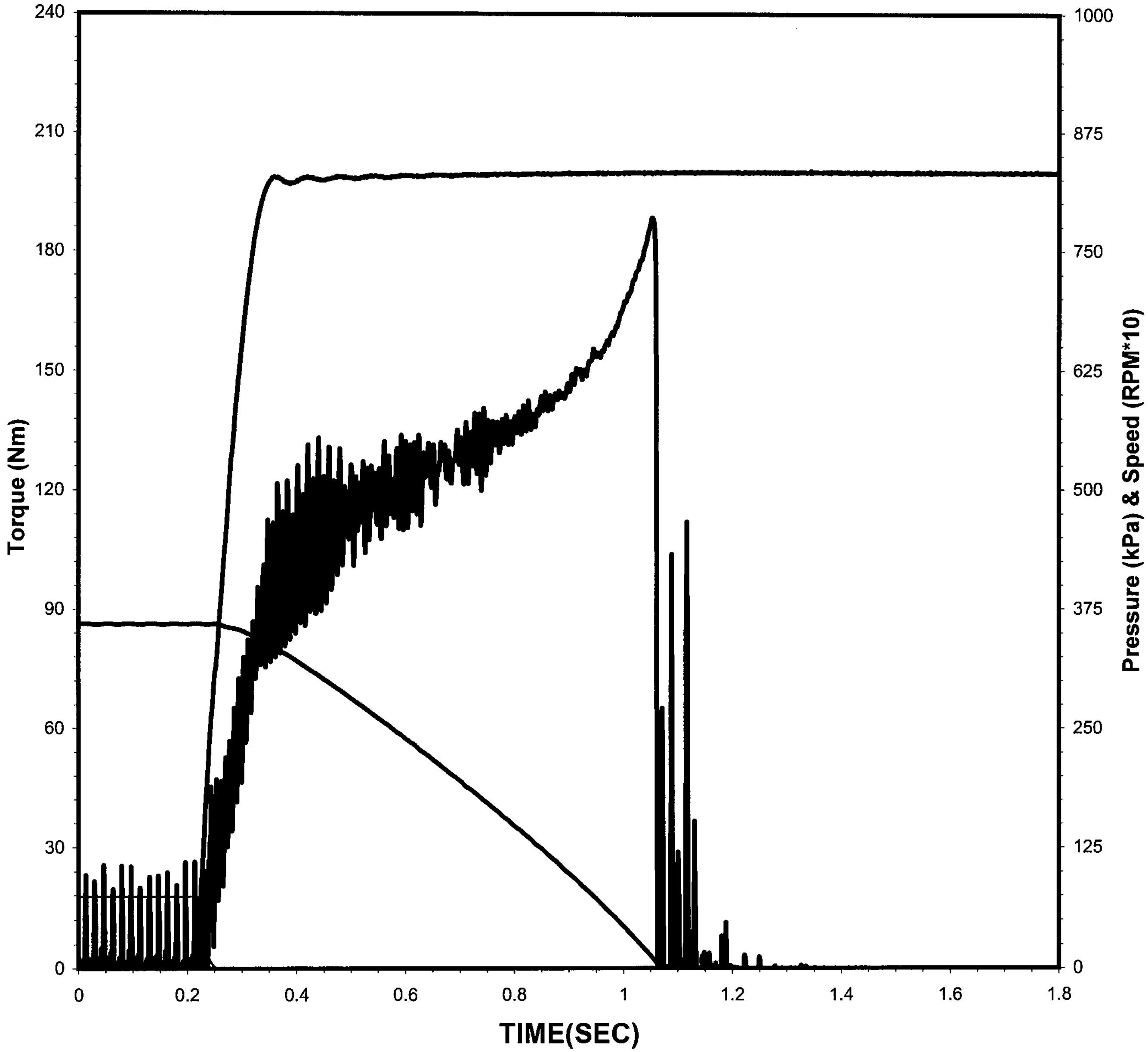
0.2 Sec Dyn:	**109 N*m**
Midpoint Dyn:	**124 N*m**
LwSpd Dynamic:	**184 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.075**
Midpoint Dyn:	**0.086**
LwSpd Dynamic:	**0.127**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	21:59:01
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	2001
Temperature:	109.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.844 Sec

Torque

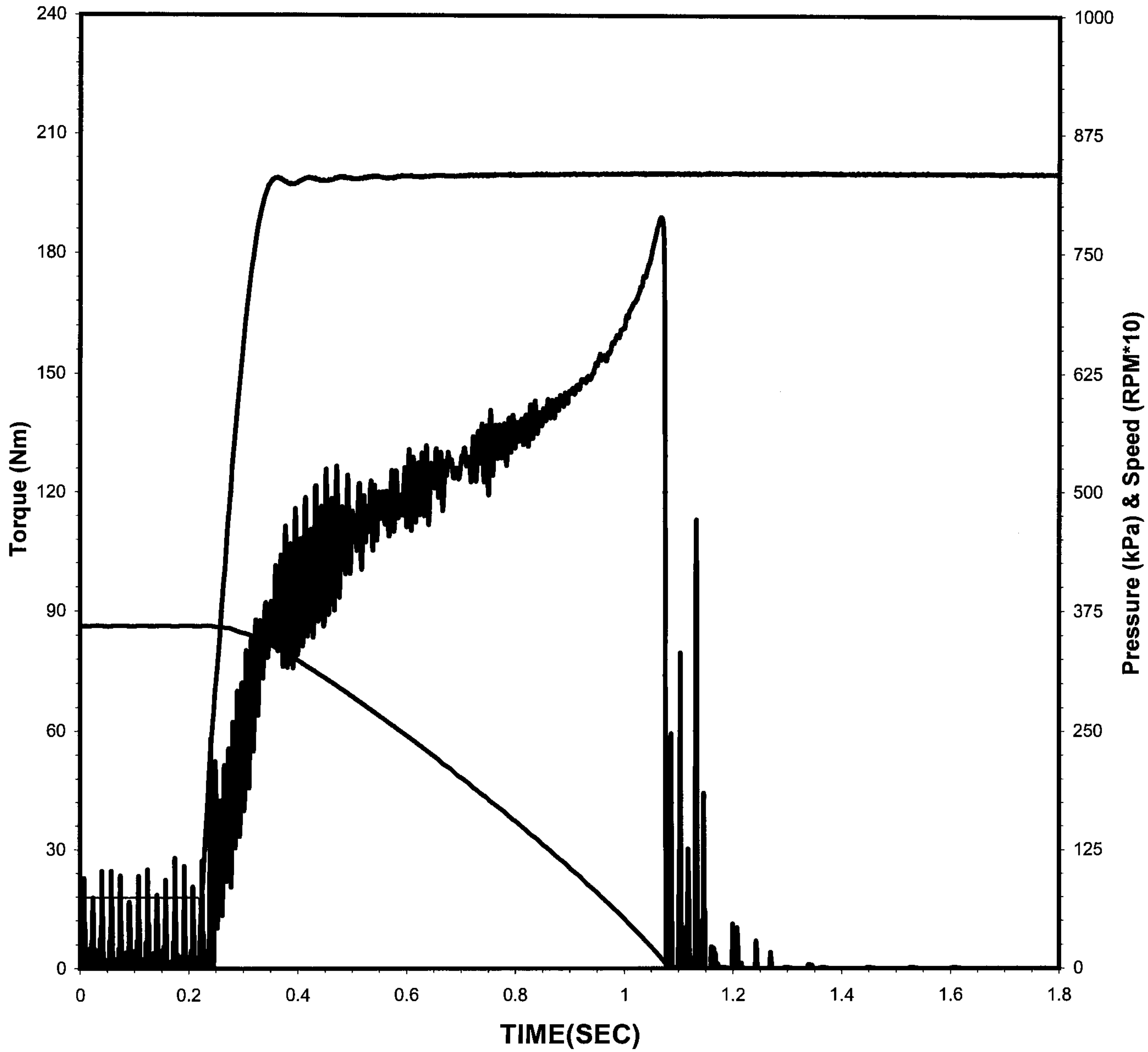
0.2 Sec Dyn:	107 N*m
Midpoint Dyn:	125 N*m
LwSpd Dynamic:	182 N*m

Coefficient of Friction

.2 Sec Dyn:	0.074
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/22/2010

Time of Test: 0:03:31

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 2499

Temperature: 114.2 °C
(112.7 ± 3.0 °C)

Apply Pressure: 831 kPa
827 ± 7 KPa)

Apply Rate: 0.14 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.858 Sec

Torque

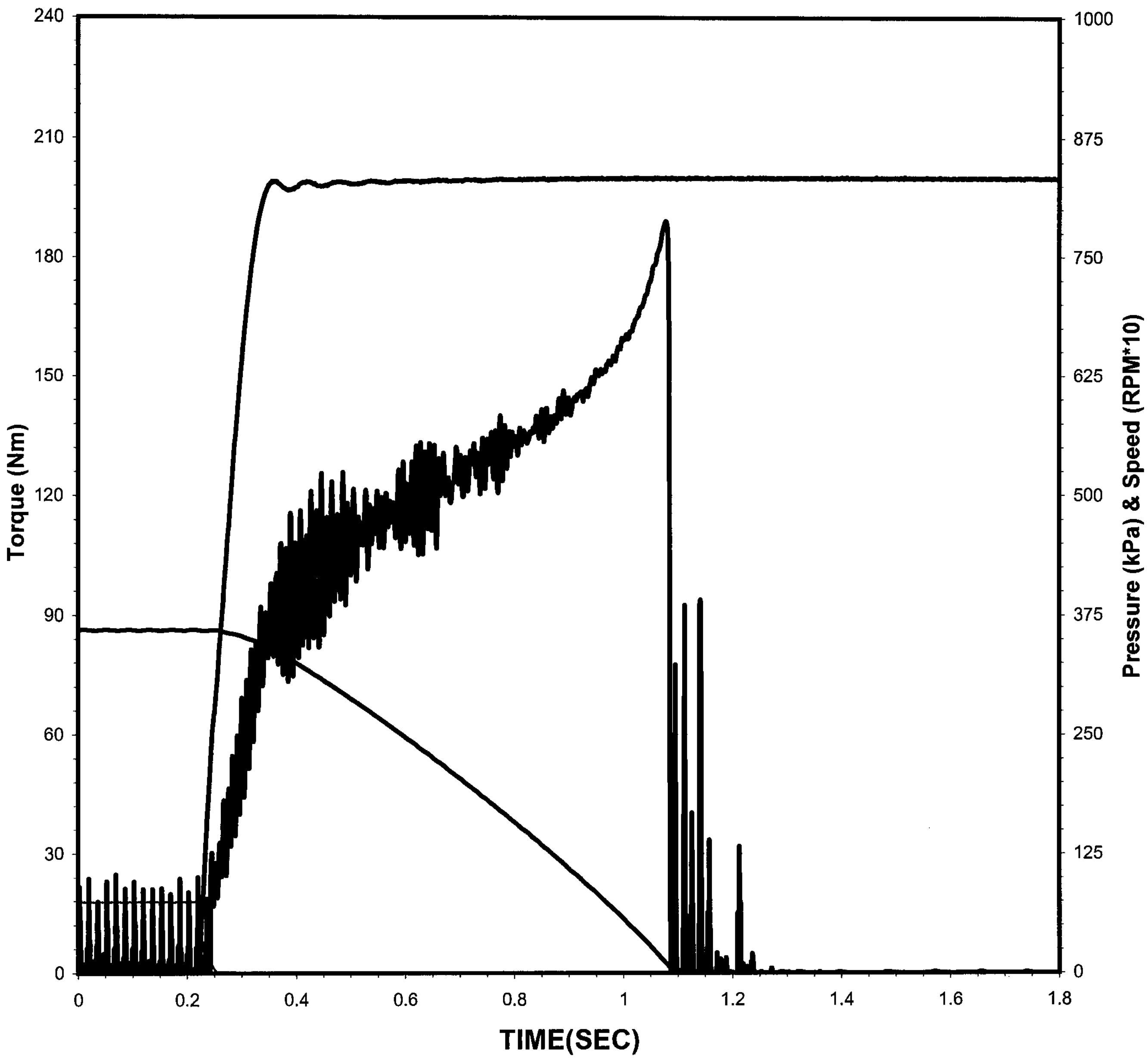
0.2 Sec Dyn:	102 N*m
Midpoint Dyn:	123 N*m
LwSpd Dynamic:	185 N*m

Coefficient of Friction

.2 Sec Dyn:	0.071
Midpoint Dyn:	0.085
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/22/2010

Time of Test: 0:03:46

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 2500

Temperature: 114.4 °C
(112.7 ± 3.0 °C)

Apply Pressure: 831 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.863 Sec

Torque

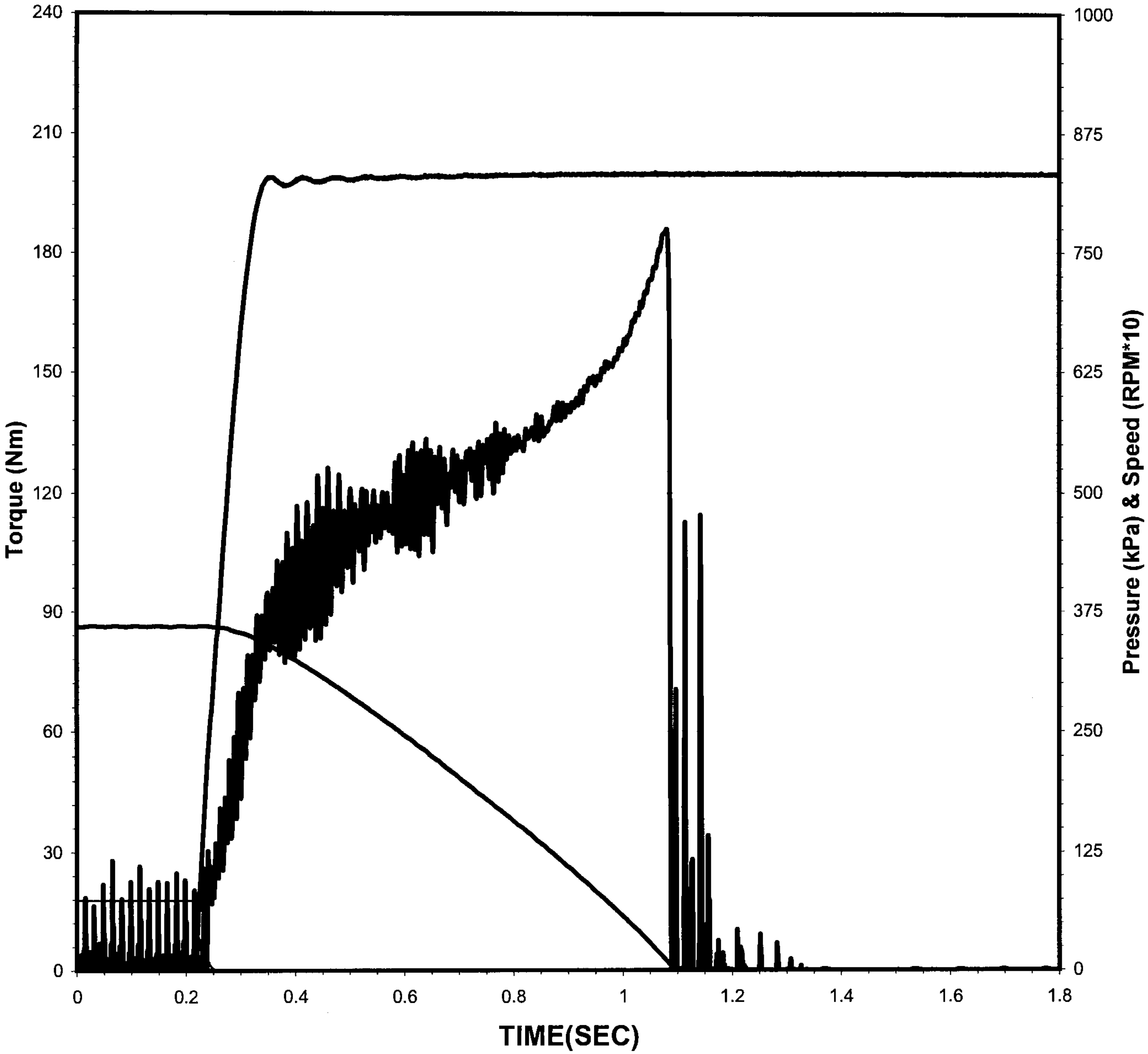
0.2 Sec Dyn:	**102 N*m**
Midpoint Dyn:	**122 N*m**
LwSpd Dynamic:	**186 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.070**
Midpoint Dyn:	**0.084**
LwSpd Dynamic:	**0.129**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/22/2010**
Time of Test:	**0:04:12**
Test Number:	**C4-8-1286**
Fluid Code:	**LO253071**
Cycle Number:	**2501**
Temperature:	**109.8 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**831 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.869 Sec**

Torque

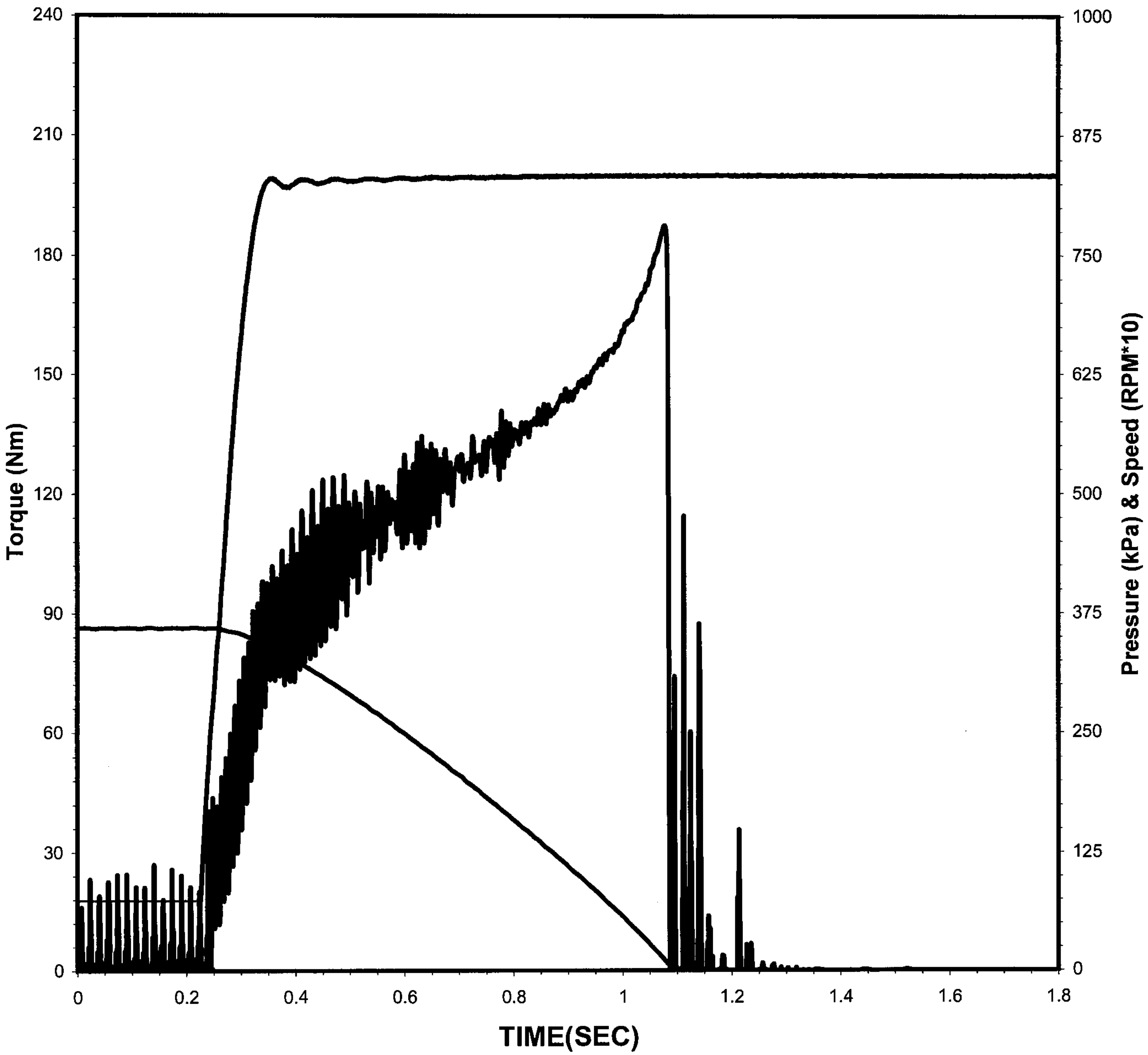
0.2 Sec Dyn:	**101 N*m**
Midpoint Dyn:	**122 N*m**
LwSpd Dynamic:	**181 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.070**
Midpoint Dyn:	**0.084**
LwSpd Dynamic:	**0.125**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/22/2010**
Time of Test:	**2:08:43**
Test Number:	**C4-8-1286**
Fluid Code:	**LO253071**
Cycle Number:	**2999**
Temperature:	**114.4 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**832 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.866 Sec**

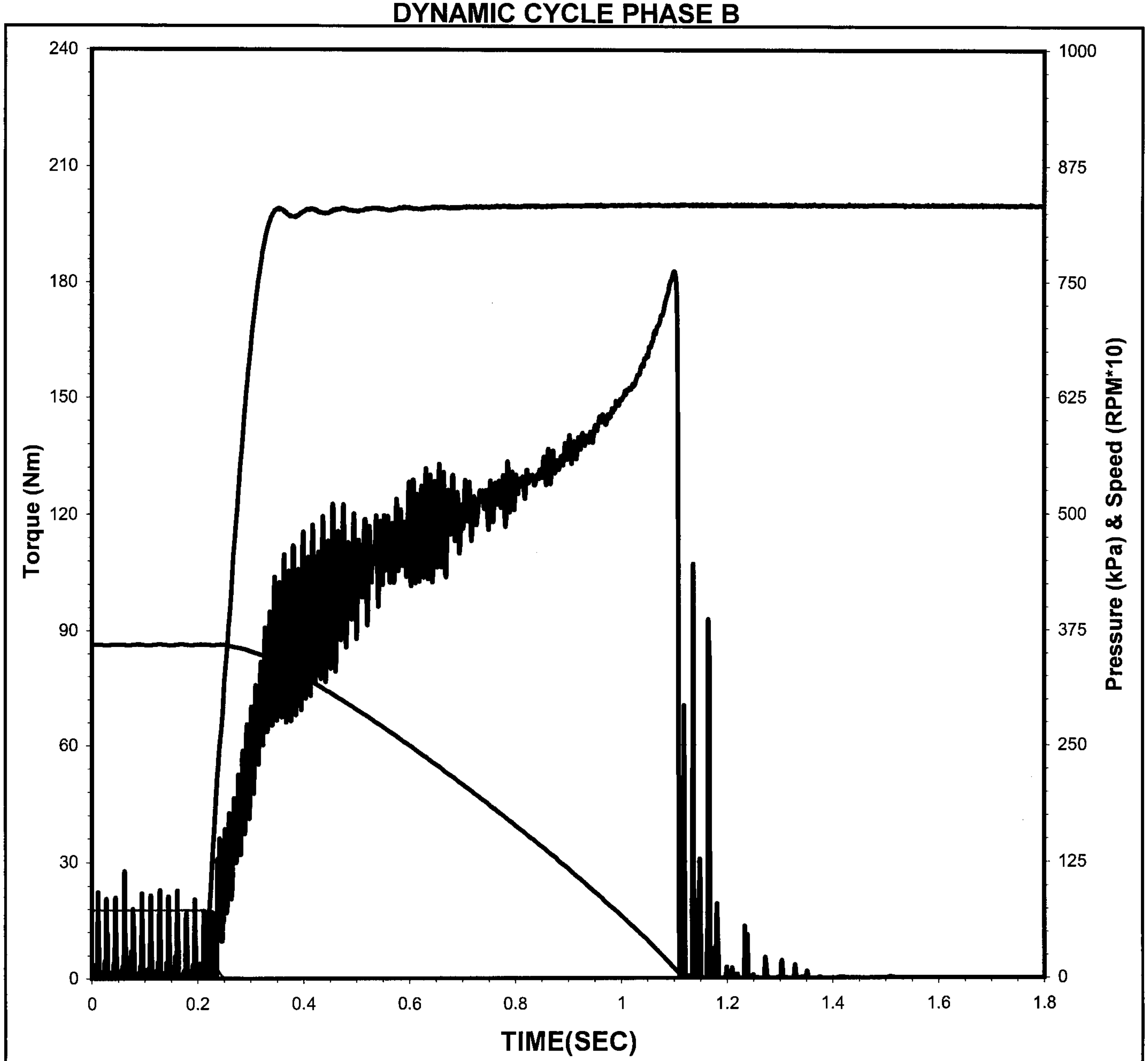
Torque

0.2 Sec Dyn:	**96 N*m**
Midpoint Dyn:	**123 N*m**
LwSpd Dynamic:	**184 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.066**
Midpoint Dyn:	**0.085**
LwSpd Dynamic:	**0.127**

ALLISON C-4 GRAPHITE DATA



Date of Test:	7/22/2010
Time of Test:	2:08:58
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	3000
Temperature:	114.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.893 Sec

Torque

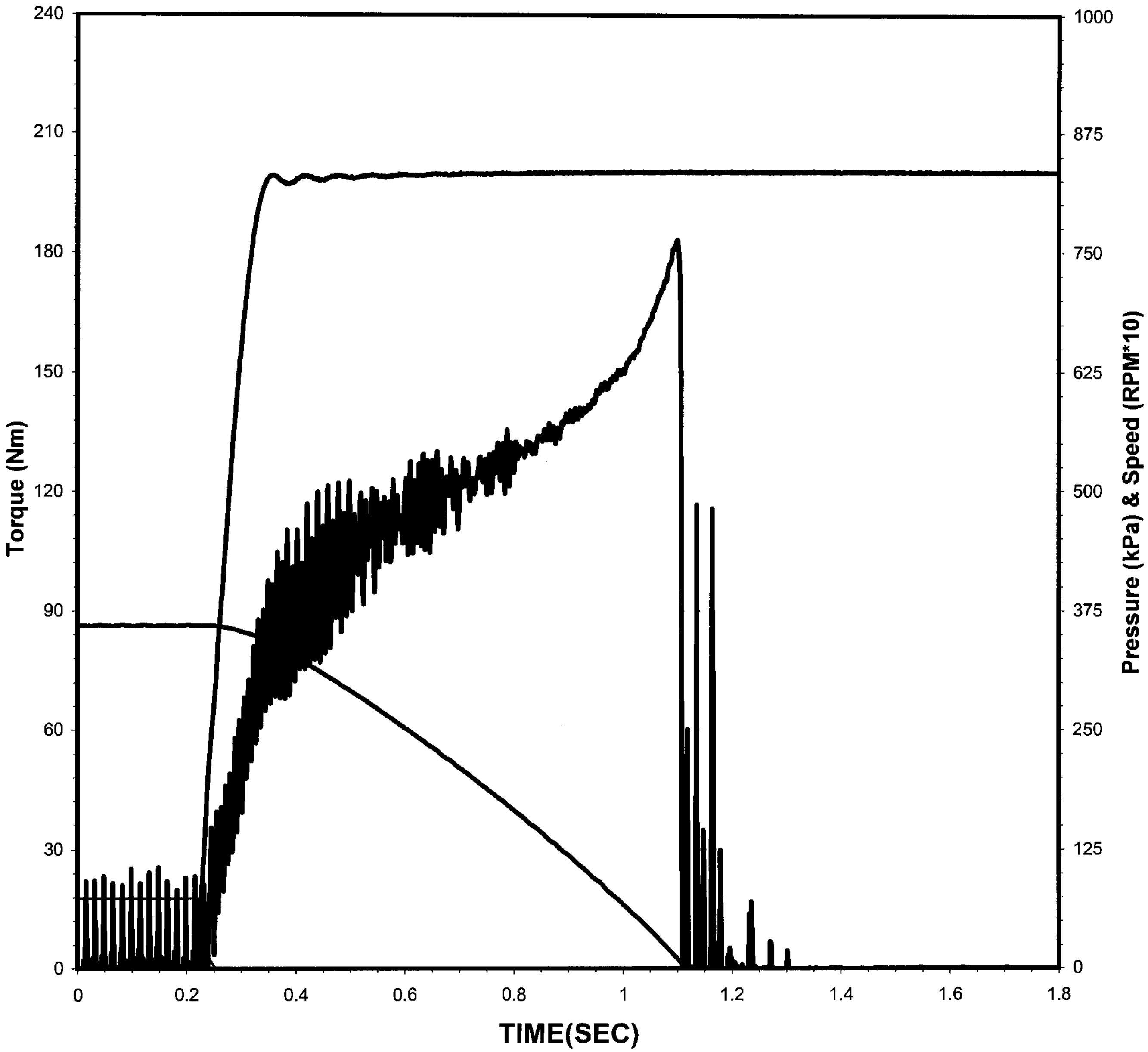
0.2 Sec Dyn:	94 N*m
Midpoint Dyn:	119 N*m
LwSpd Dynamic:	177 N*m

Coefficient of Friction

.2 Sec Dyn:	0.065
Midpoint Dyn:	0.083
LwSpd Dynamic:	0.122

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: **7/22/2010**

Time of Test: **2:09:24**

Test Number: **C4-8-1286**

Fluid Code: **LO253071**

Cycle Number: **3001**

Temperature: **110.1 °C**
(112.7 ± 3.0 °C)

Apply Pressure: **832 kPa**
827 ± 7 KPa)

Apply Rate: **0.13 Sec**
(0.15 ± 0.02 Sec)

Energy: **18.4 KJ**
(18.71 ± 0.40 KJ)

Engage Time: **0.888 Sec**

Torque

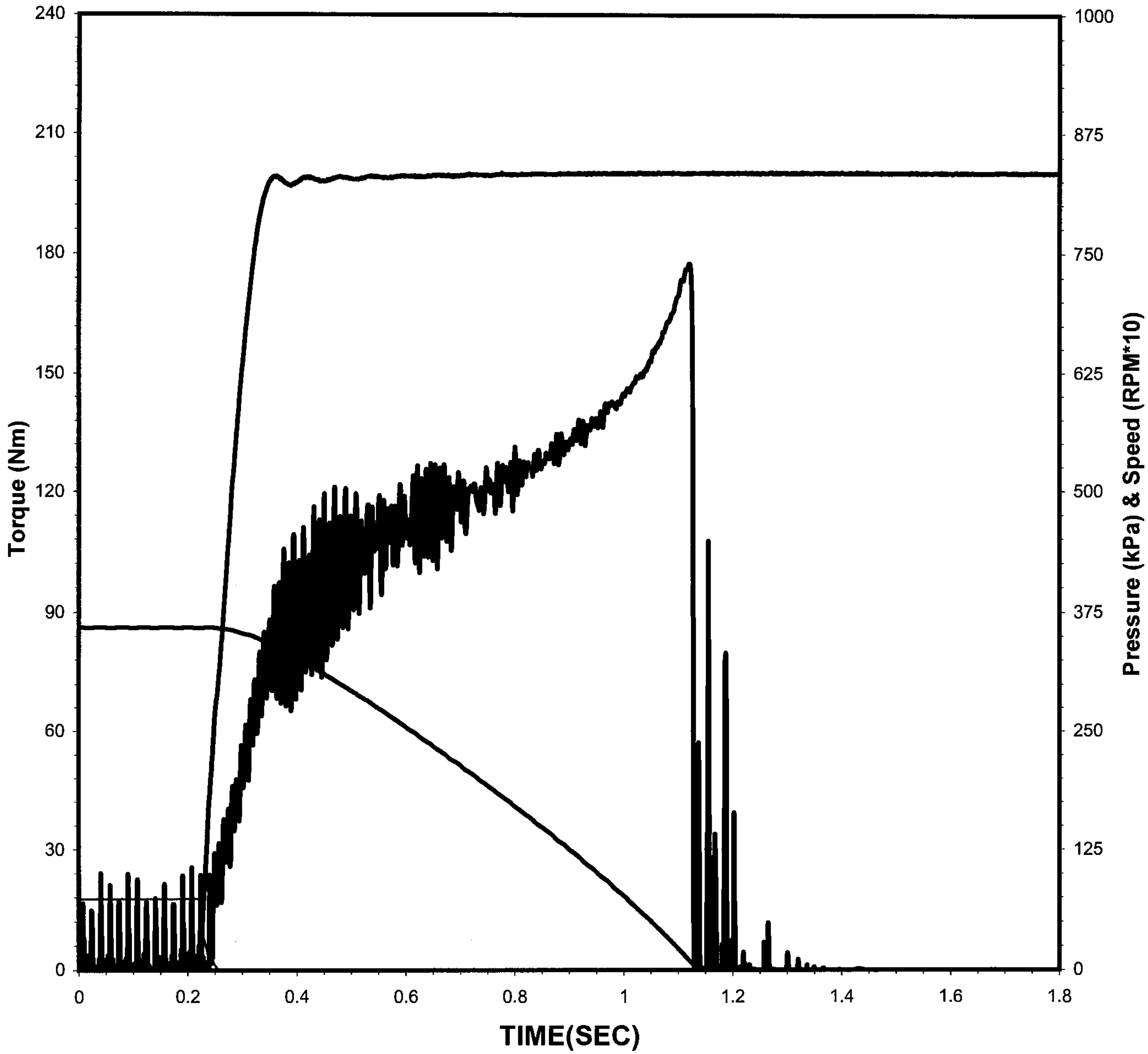
0.2 Sec Dyn:	95 N*m
Midpoint Dyn:	120 N*m
LwSpd Dynamic:	176 N*m

Coefficient of Friction

.2 Sec Dyn:	0.066
Midpoint Dyn:	0.083
LwSpd Dynamic:	0.122

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	4:13:54
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	3499
Temperature:	114.1 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	832 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.905 Sec

Torque

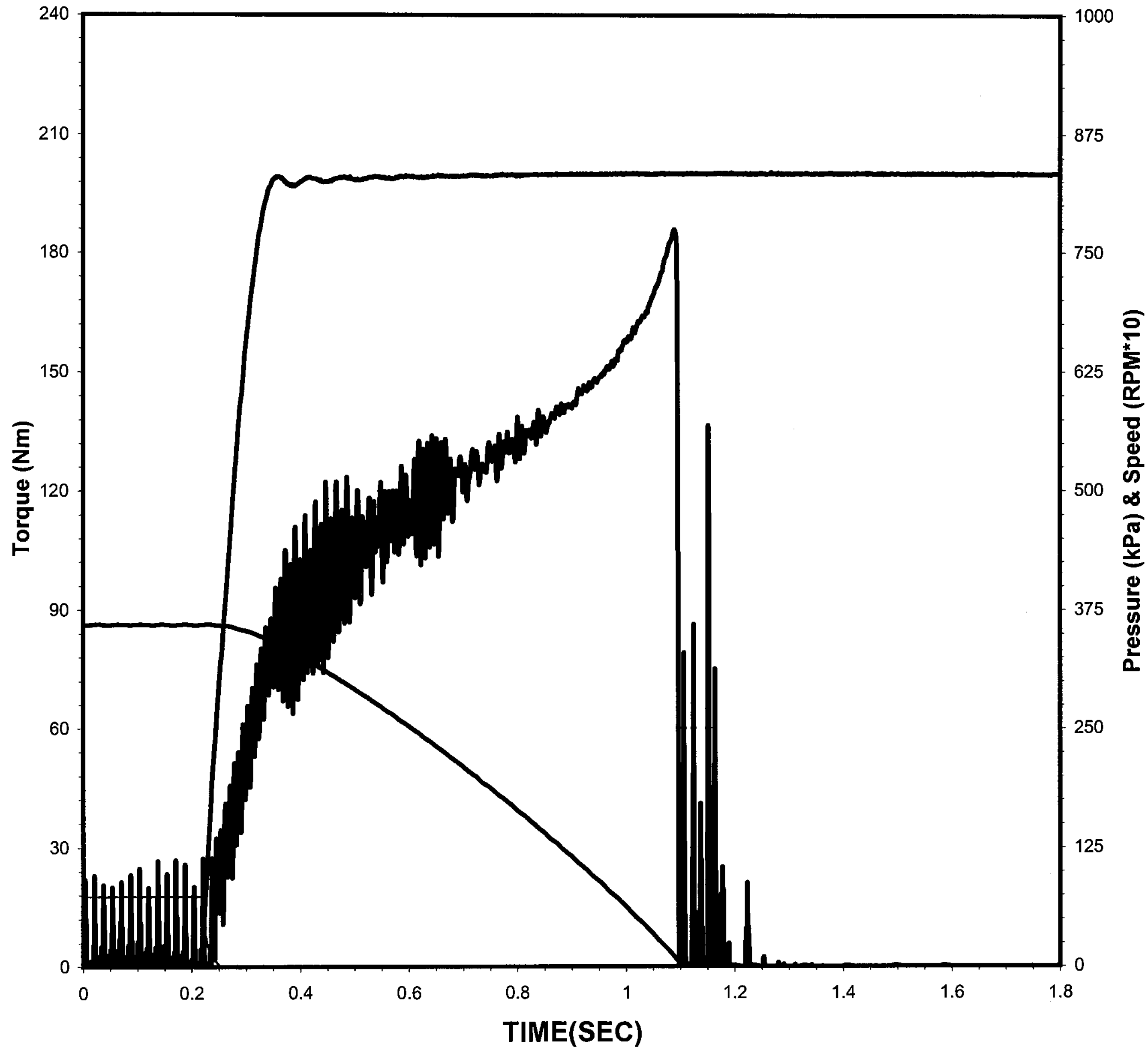
0.2 Sec Dyn:	96 N*m
Midpoint Dyn:	117 N*m
LwSpd Dynamic:	171 N*m

Coefficient of Friction

.2 Sec Dyn:	0.066
Midpoint Dyn:	0.081
LwSpd Dynamic:	0.118

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	4:14:09
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	3500
Temperature:	114.6 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	831 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.877 Sec

Torque

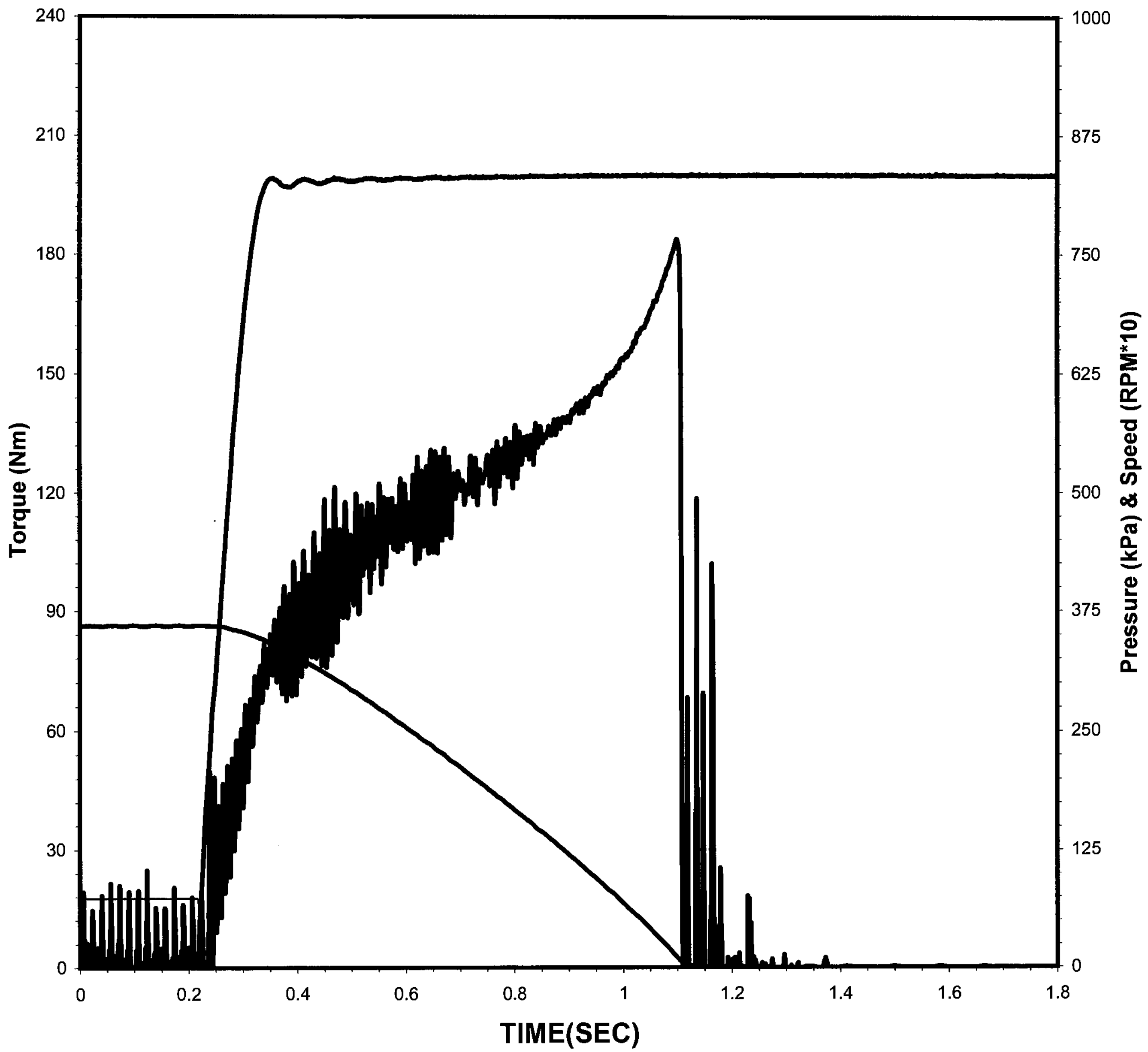
0.2 Sec Dyn:	96 N*m
Midpoint Dyn:	121 N*m
LwSpd Dynamic:	179 N*m

Coefficient of Friction

.2 Sec Dyn:	0.066
Midpoint Dyn:	0.084
LwSpd Dynamic:	0.124

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/22/2010**
Time of Test:	**4:14:36**
Test Number:	**C4-8-1286**
Fluid Code:	**LO253071**
Cycle Number:	**3501**
Temperature:	**109.6 °C**
	(112.7 ± 3.0 °C)
Apply Pressure:	**831 kPa**
	827 ± 7 KPa)
Apply Rate:	**0.13 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.4 KJ**
	(18.71 ± 0.40 KJ)
Engage Time:	**0.891 Sec**

Torque

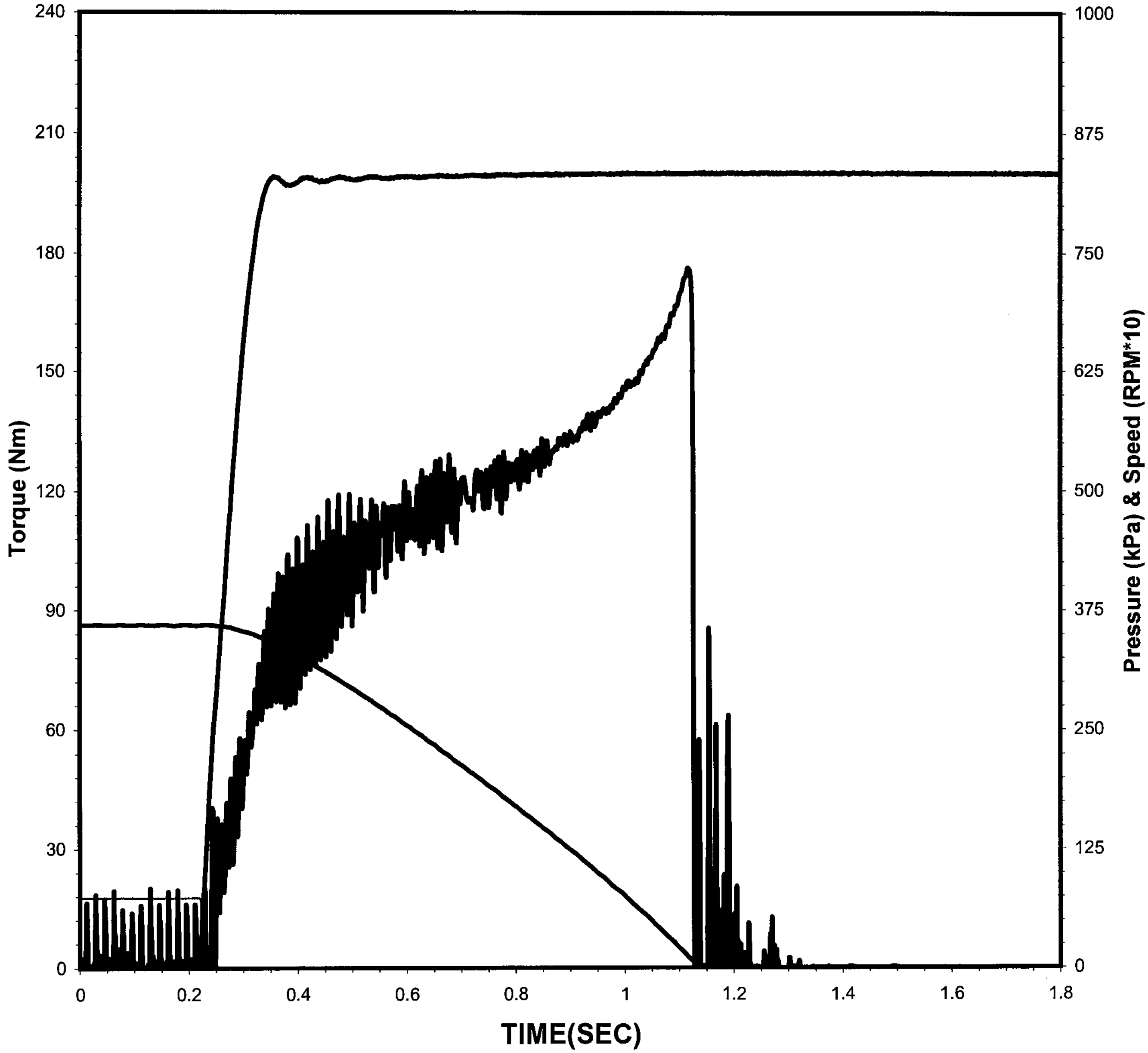
0.2 Sec Dyn:	**91 N*m**
Midpoint Dyn:	**119 N*m**
LwSpd Dynamic:	**179 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.063**
Midpoint Dyn:	**0.082**
LwSpd Dynamic:	**0.123**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	6:19:06
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	3999
Temperature:	114.1 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	831 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.905 Sec

Torque

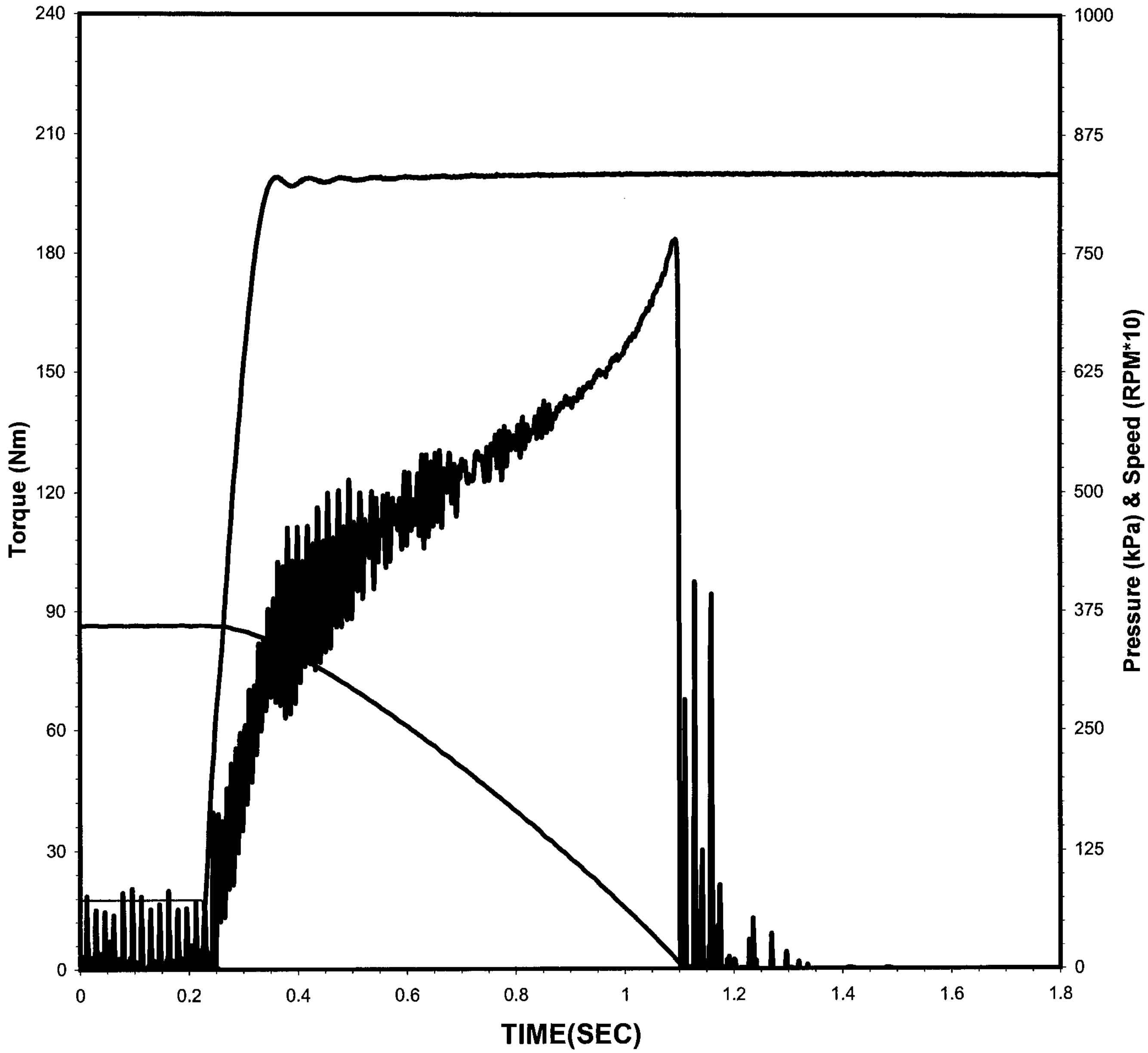
0.2 Sec Dyn:	94 N*m
Midpoint Dyn:	118 N*m
LwSpd Dynamic:	168 N*m

Coefficient of Friction

.2 Sec Dyn:	0.065
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.116

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/22/2010**
Time of Test:	**6:19:21**
Test Number:	**C4-8-1286**
Fluid Code:	**LO253071**
Cycle Number:	**4000**
Temperature:	**114.3 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**831 kPa** 827 ± 7 KPa)
Apply Rate:	**0.14 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.877 Sec**

Torque

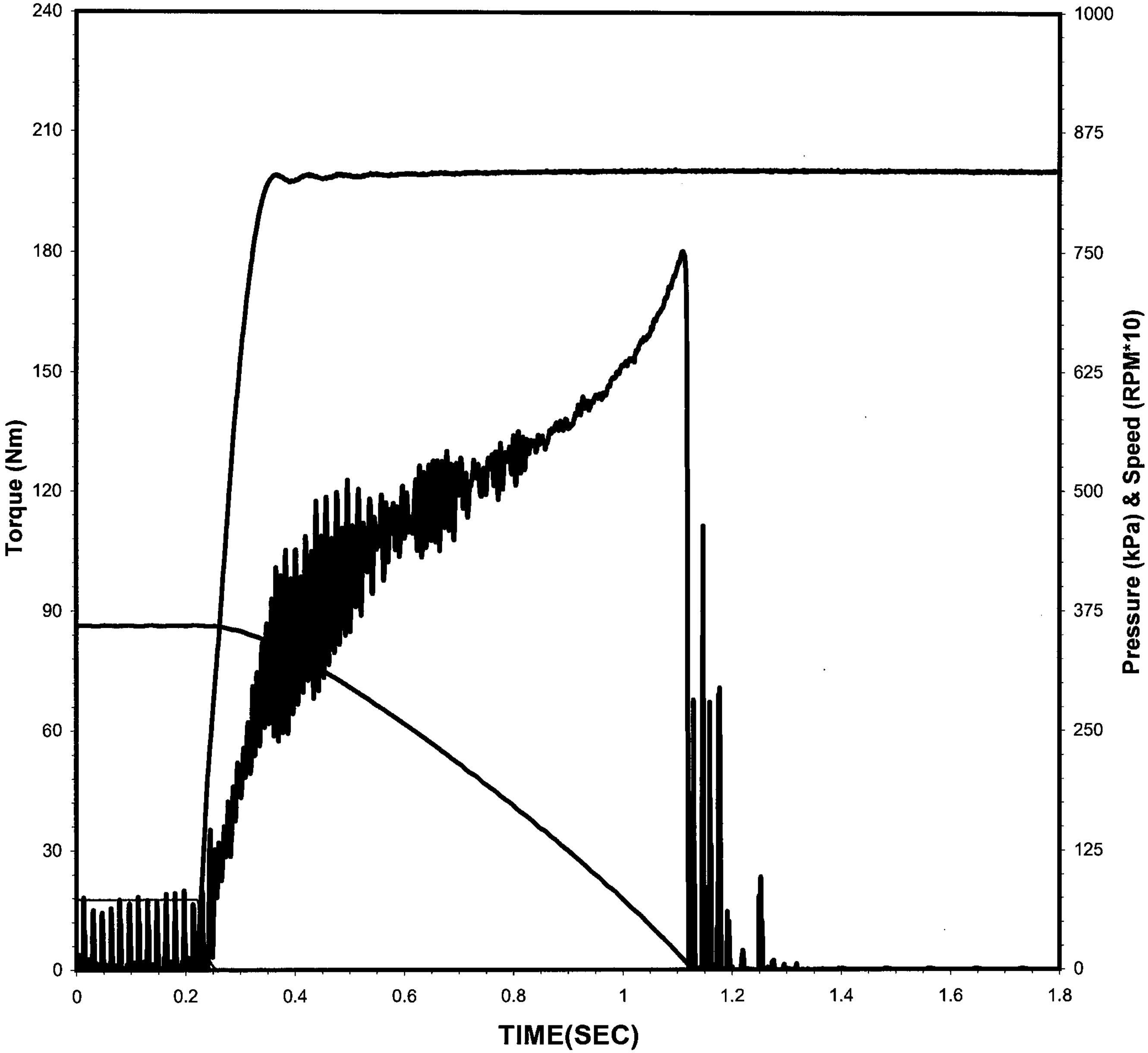
0.2 Sec Dyn:	**94 N*m**
Midpoint Dyn:	**121 N*m**
LwSpd Dynamic:	**177 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.065**
Midpoint Dyn:	**0.084**
LwSpd Dynamic:	**0.123**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	6:19:48
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	4001
Temperature:	109.7 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	832 kPa
	827 ± 7 KPa)
Apply Rate:	0.14 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.897 Sec

Torque

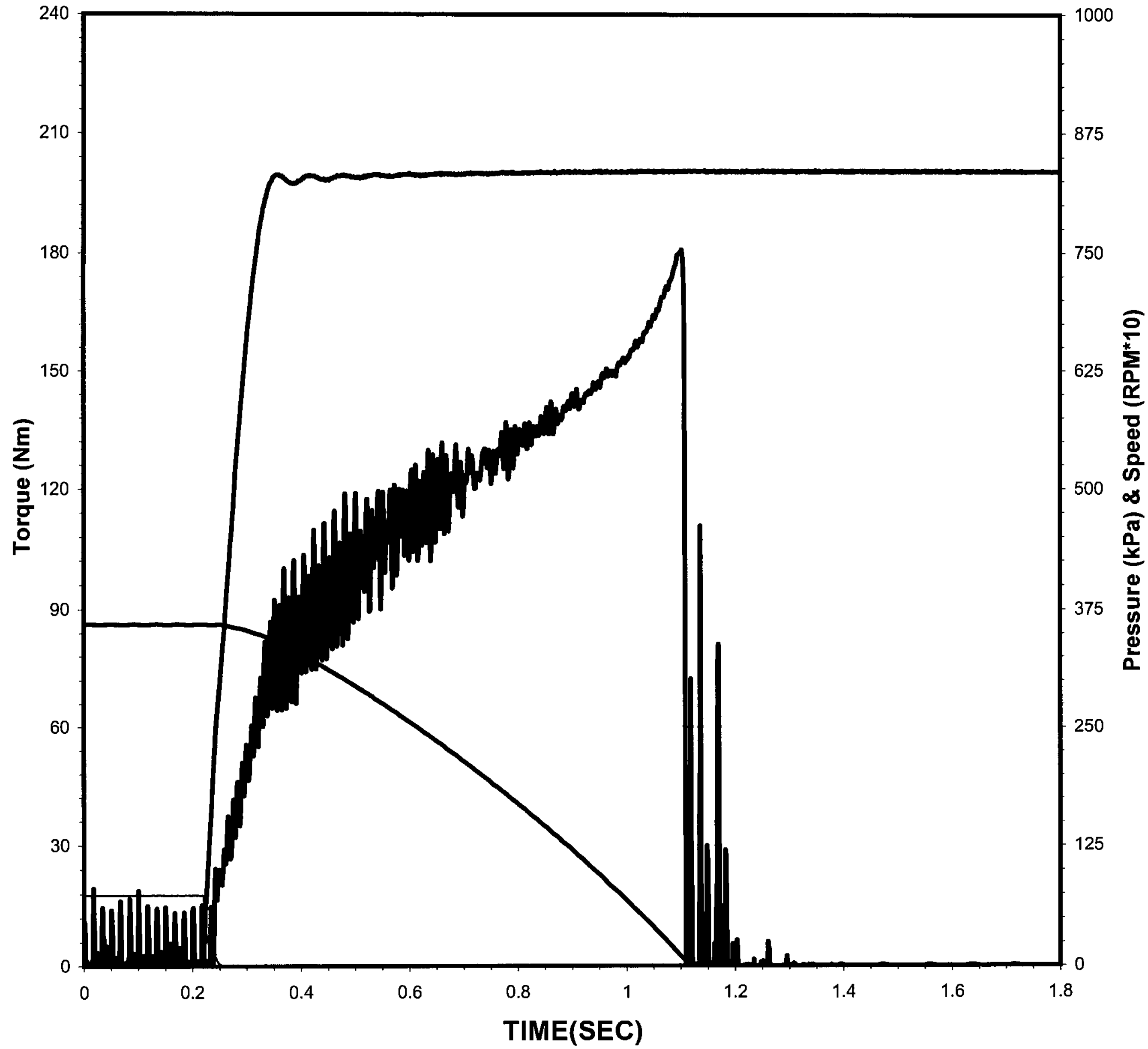
0.2 Sec Dyn:	92 N*m
Midpoint Dyn:	118 N*m
LwSpd Dynamic:	176 N*m

Coefficient of Friction

.2 Sec Dyn:	0.064
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.122

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	8:24:18
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	4499
Temperature:	114.2 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	832 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.889 Sec

Torque

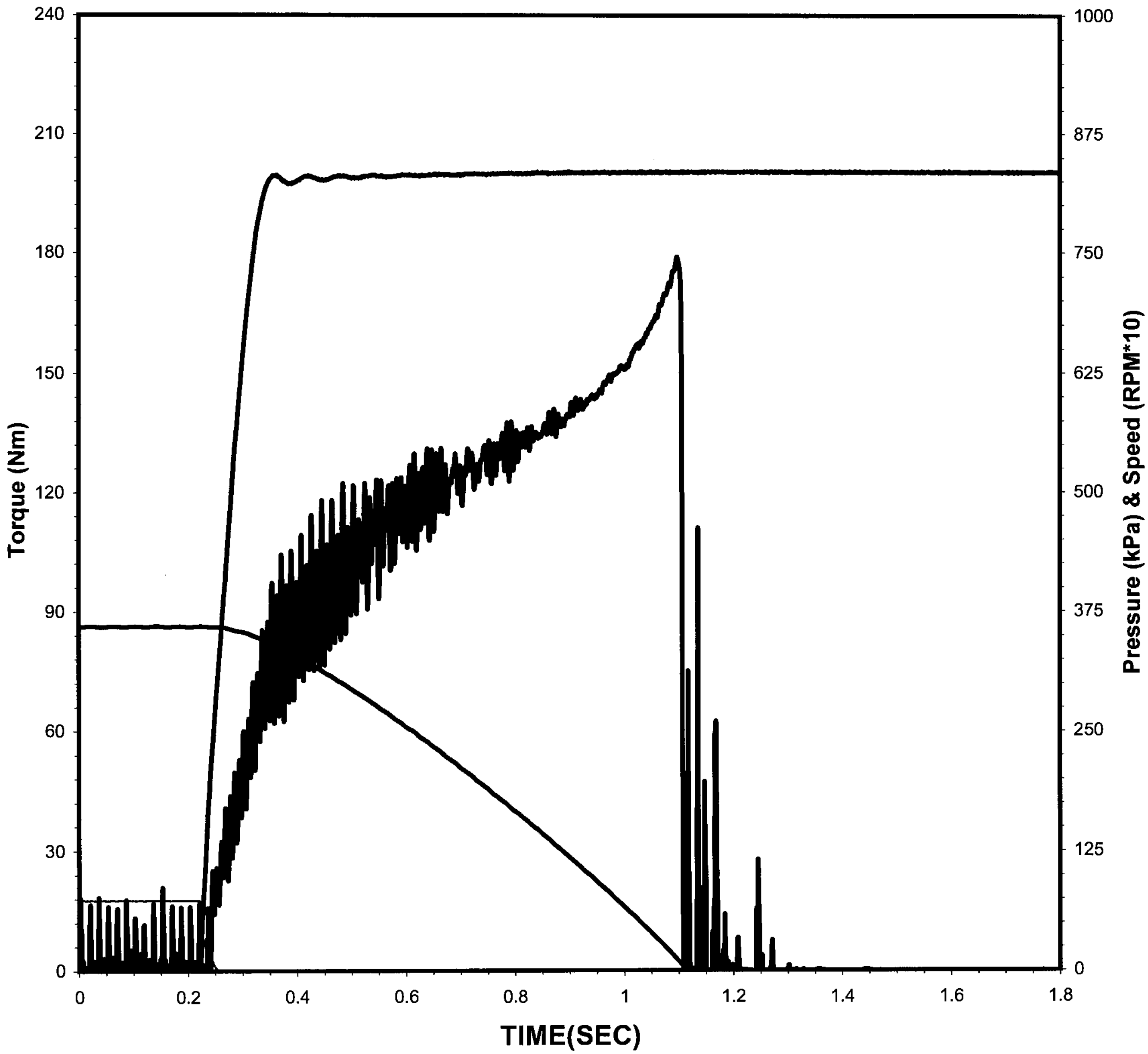
0.2 Sec Dyn:	91 N*m
Midpoint Dyn:	120 N*m
LwSpd Dynamic:	173 N*m

Coefficient of Friction

.2 Sec Dyn:	0.063
Midpoint Dyn:	0.083
LwSpd Dynamic:	0.119

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	8:24:33
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	4500
Temperature:	114.3 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	832 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.885 Sec

Torque

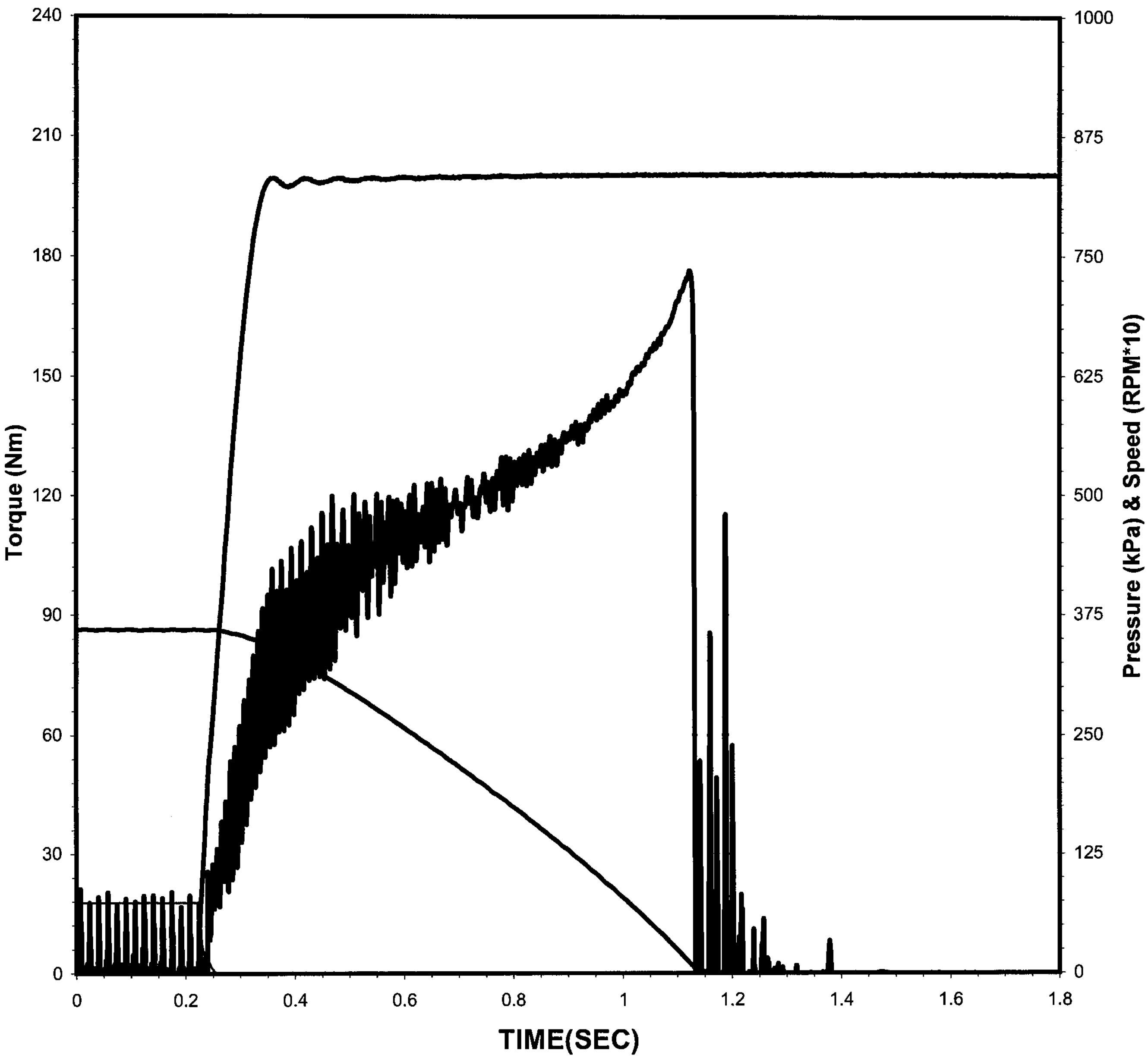
0.2 Sec Dyn:	93 N*m
Midpoint Dyn:	122 N*m
LwSpd Dynamic:	175 N*m

Coefficient of Friction

.2 Sec Dyn:	0.064
Midpoint Dyn:	0.084
LwSpd Dynamic:	0.121

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/22/2010

Time of Test: 8:25:00

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 4501

Temperature: 110.4 °C
(112.7 ± 3.0 °C)
Apply Pressure: 832 kPa
827 ± 7 KPa)
Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)
Energy: 18.4 KJ
(18.71 ± 0.40 KJ)
Engage Time: 0.909 Sec

Torque

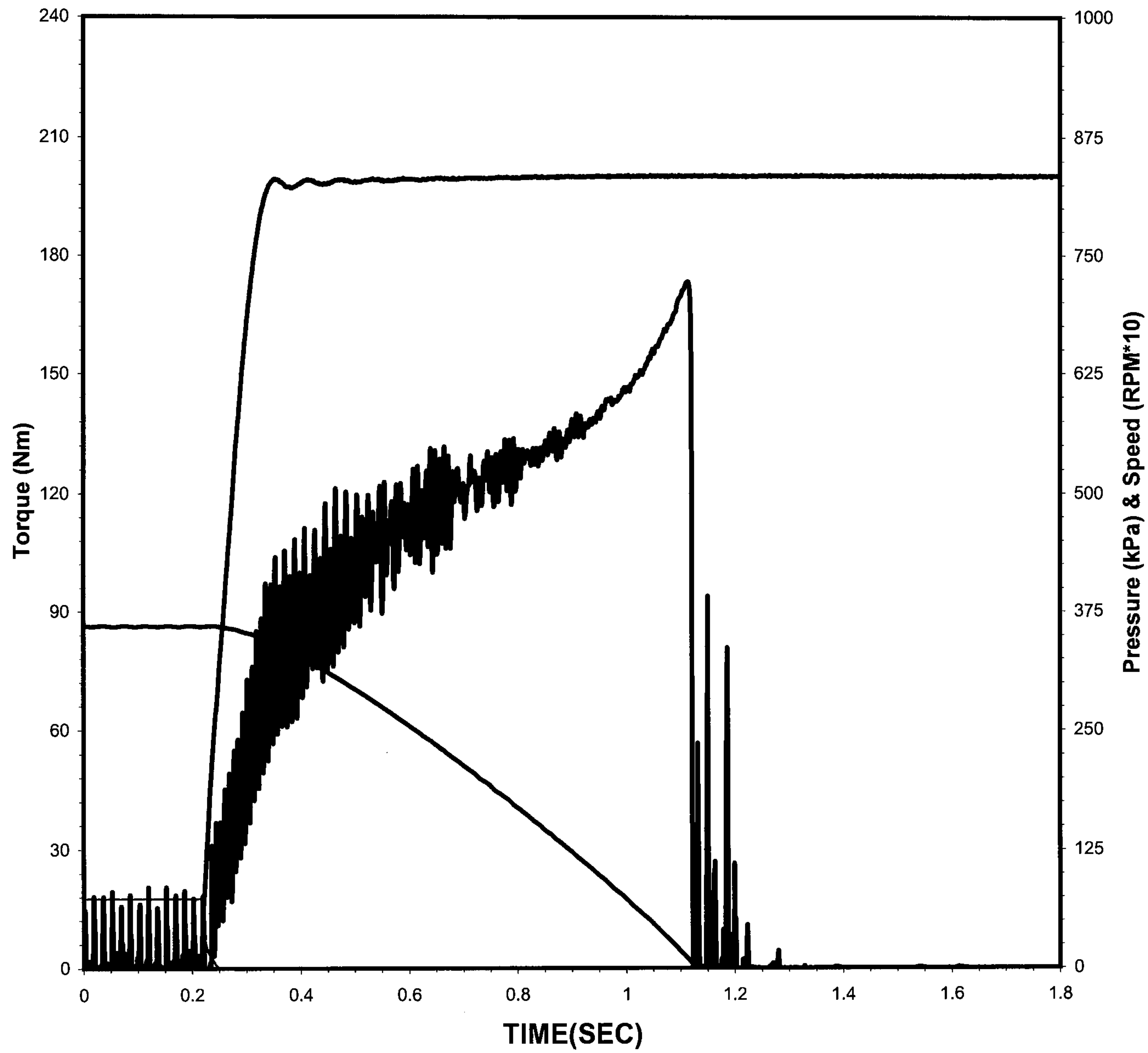
0.2 Sec Dyn:	92 N*m
Midpoint Dyn:	116 N*m
LwSpd Dynamic:	172 N*m

Coefficient of Friction

.2 Sec Dyn:	0.063
Midpoint Dyn:	0.080
LwSpd Dynamic:	0.119

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	10:29:30
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	4999
Temperature:	114.3 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.905 Sec

Torque

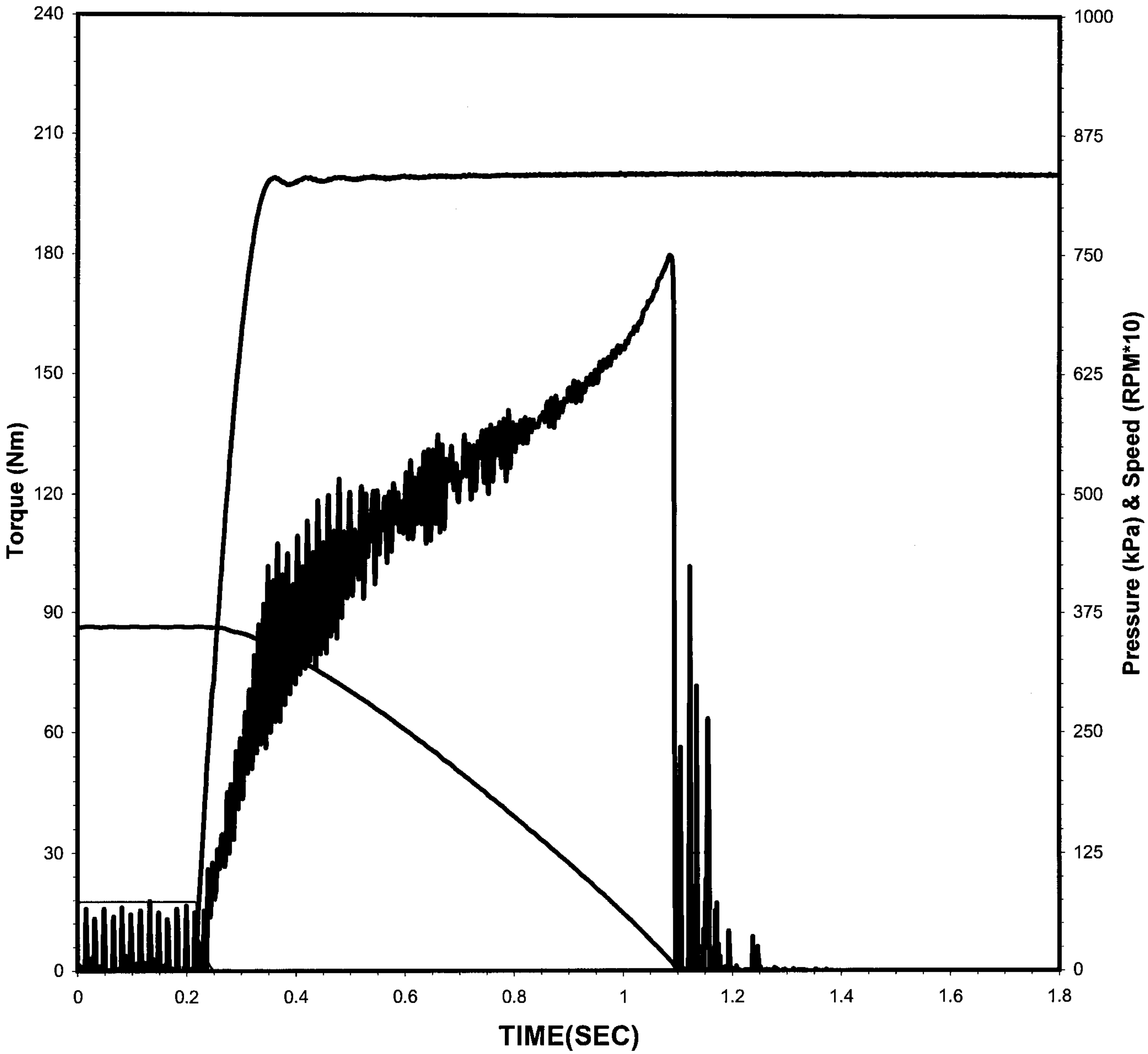
0.2 Sec Dyn:	90 N*m
Midpoint Dyn:	120 N*m
LwSpd Dynamic:	166 N*m

Coefficient of Friction

.2 Sec Dyn:	0.062
Midpoint Dyn:	0.083
LwSpd Dynamic:	0.115

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/22/2010**
Time of Test:	**10:29:45**
Test Number:	**C4-8-1286**
Fluid Code:	**LO253071**
Cycle Number:	**5000**
Temperature:	**114.3 °C**
	(112.7 ± 3.0 °C)
Apply Pressure:	**832 kPa**
	827 ± 7 KPa)
Apply Rate:	**0.14 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.4 KJ**
	(18.71 ± 0.40 KJ)
Engage Time:	**0.879 Sec**

Torque

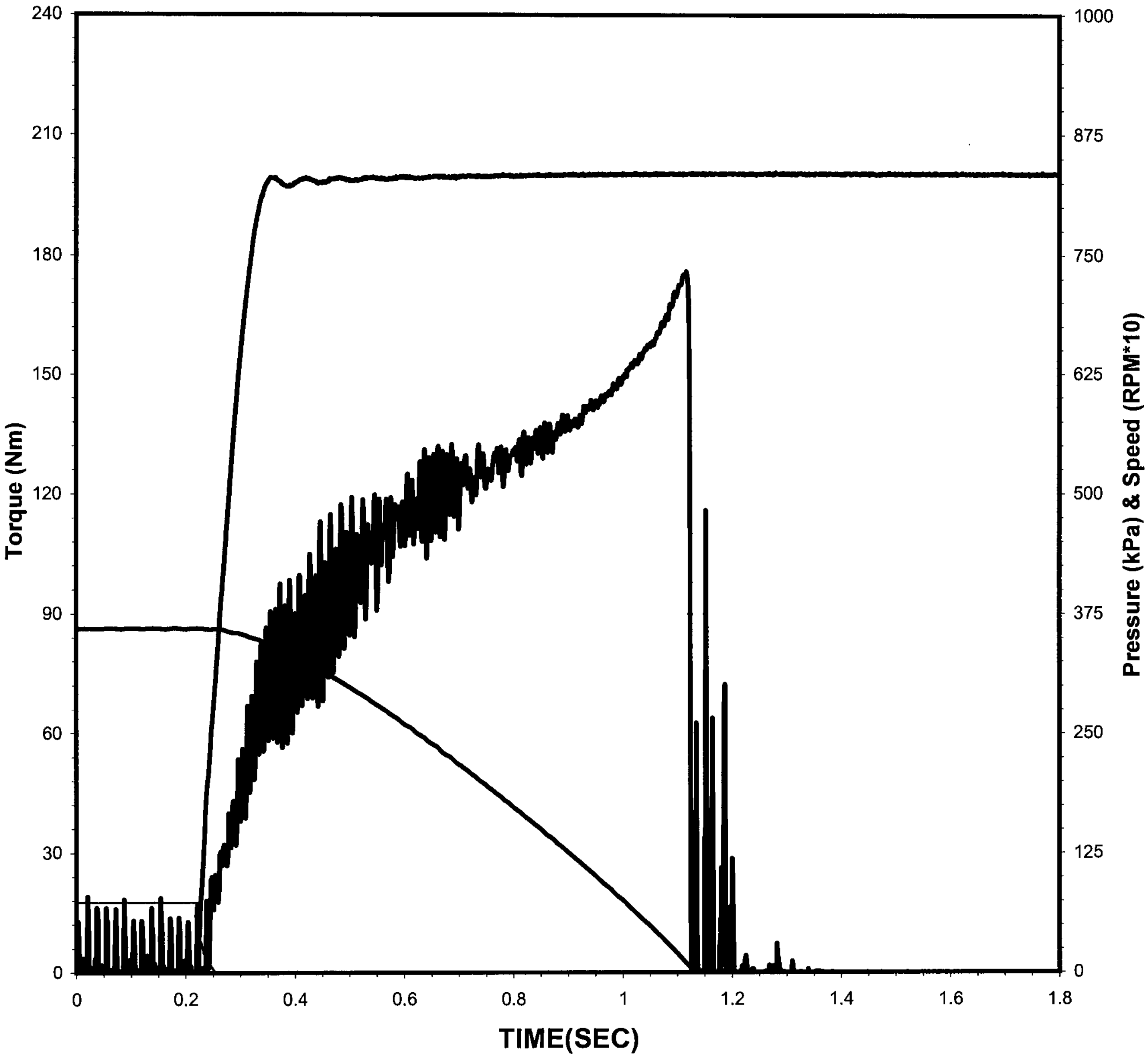
0.2 Sec Dyn:	**94 N*m**
Midpoint Dyn:	**122 N*m**
LwSpd Dynamic:	**174 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.065**
Midpoint Dyn:	**0.085**
LwSpd Dynamic:	**0.120**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/22/2010

Time of Test: 10:30:11

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 5001

Temperature: 109.7 °C
(112.7 ± 3.0 °C)

Apply Pressure: 832 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.902 Sec

Torque

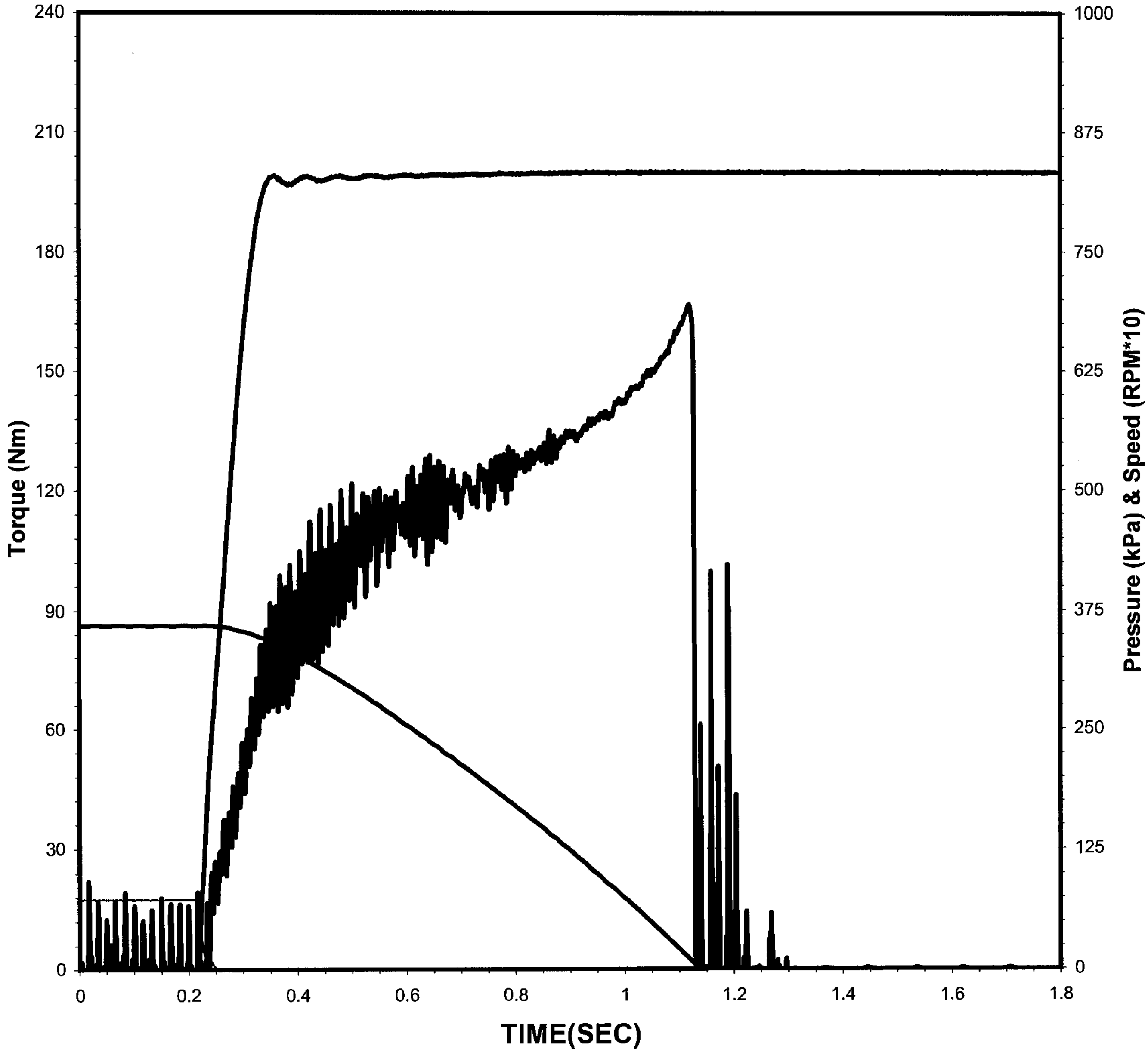
0.2 Sec Dyn:	87 N*m
Midpoint Dyn:	122 N*m
LwSpd Dynamic:	170 N*m

Coefficient of Friction

.2 Sec Dyn:	0.060
Midpoint Dyn:	0.084
LwSpd Dynamic:	0.118

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	12:34:27
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	5498
Temperature:	114.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.911 Sec

Torque

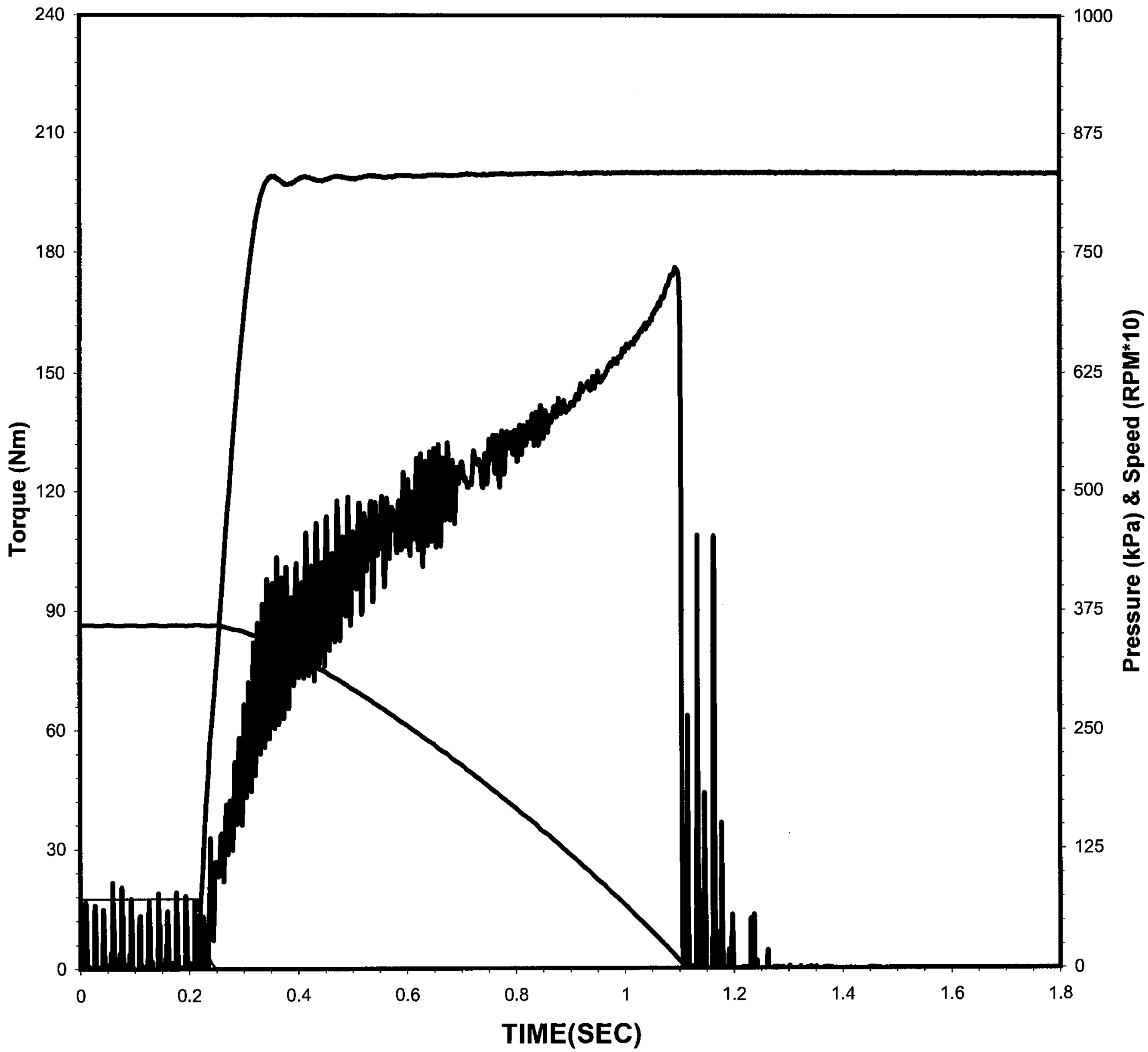
0.2 Sec Dyn:	93 N*m
Midpoint Dyn:	119 N*m
LwSpd Dynamic:	158 N*m

Coefficient of Friction

.2 Sec Dyn:	0.064
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.109

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	12:34:42
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	5499
Temperature:	114.7 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	831 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.889 Sec

Torque

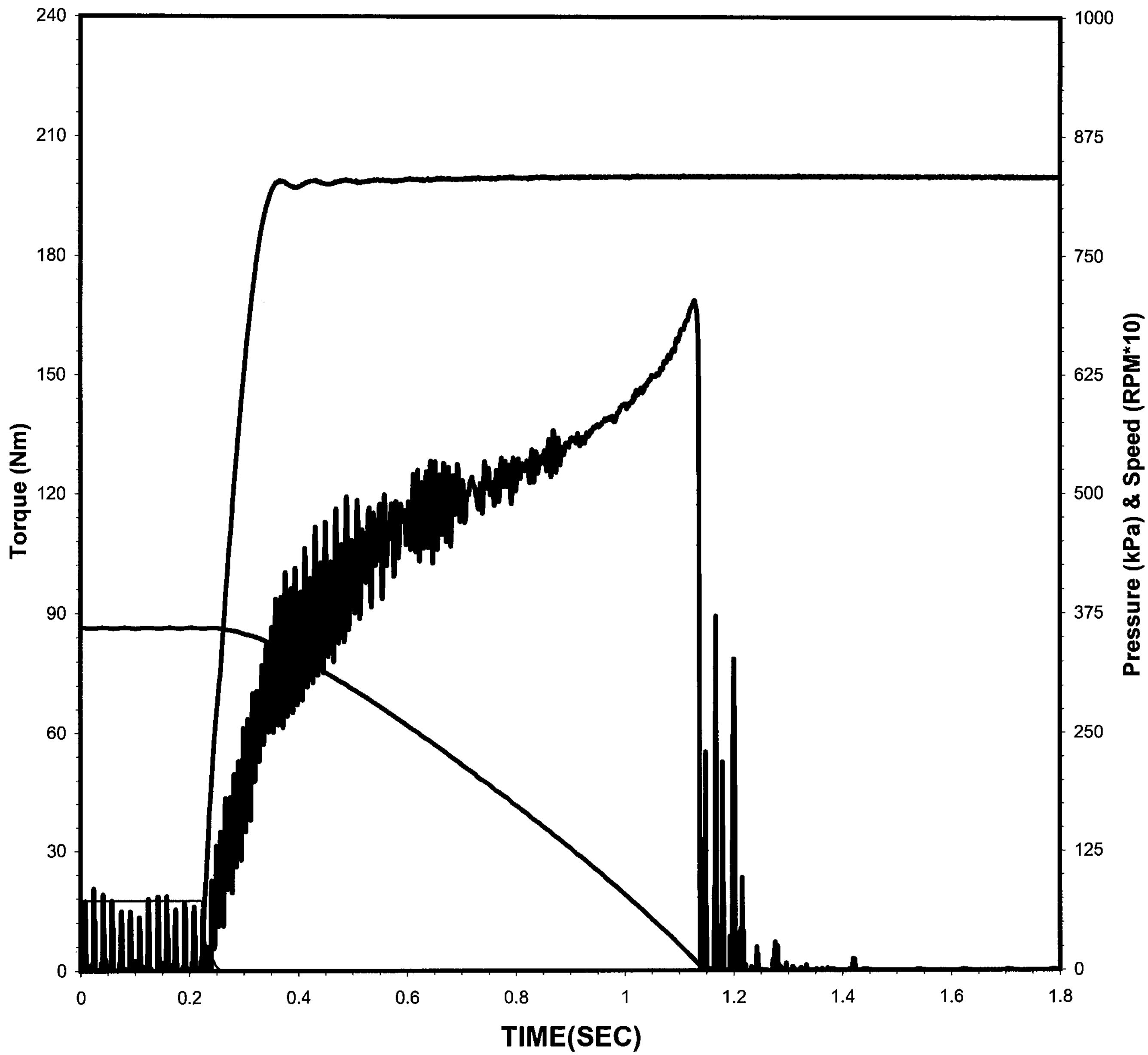
0.2 Sec Dyn:	90 N*m
Midpoint Dyn:	120 N*m
LwSpd Dynamic:	171 N*m

Coefficient of Friction

.2 Sec Dyn:	0.062
Midpoint Dyn:	0.083
LwSpd Dynamic:	0.118

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	12:34:57
Test Number:	C4-8-1286
Fluid Code:	LO253071
Cycle Number:	5500
Temperature:	114.2 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	831 kPa
	827 ± 7 KPa)
Apply Rate:	0.14 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.915 Sec

Torque

0.2 Sec Dyn:	90 N*m
Midpoint Dyn:	119 N*m
LwSpd Dynamic:	160 N*m

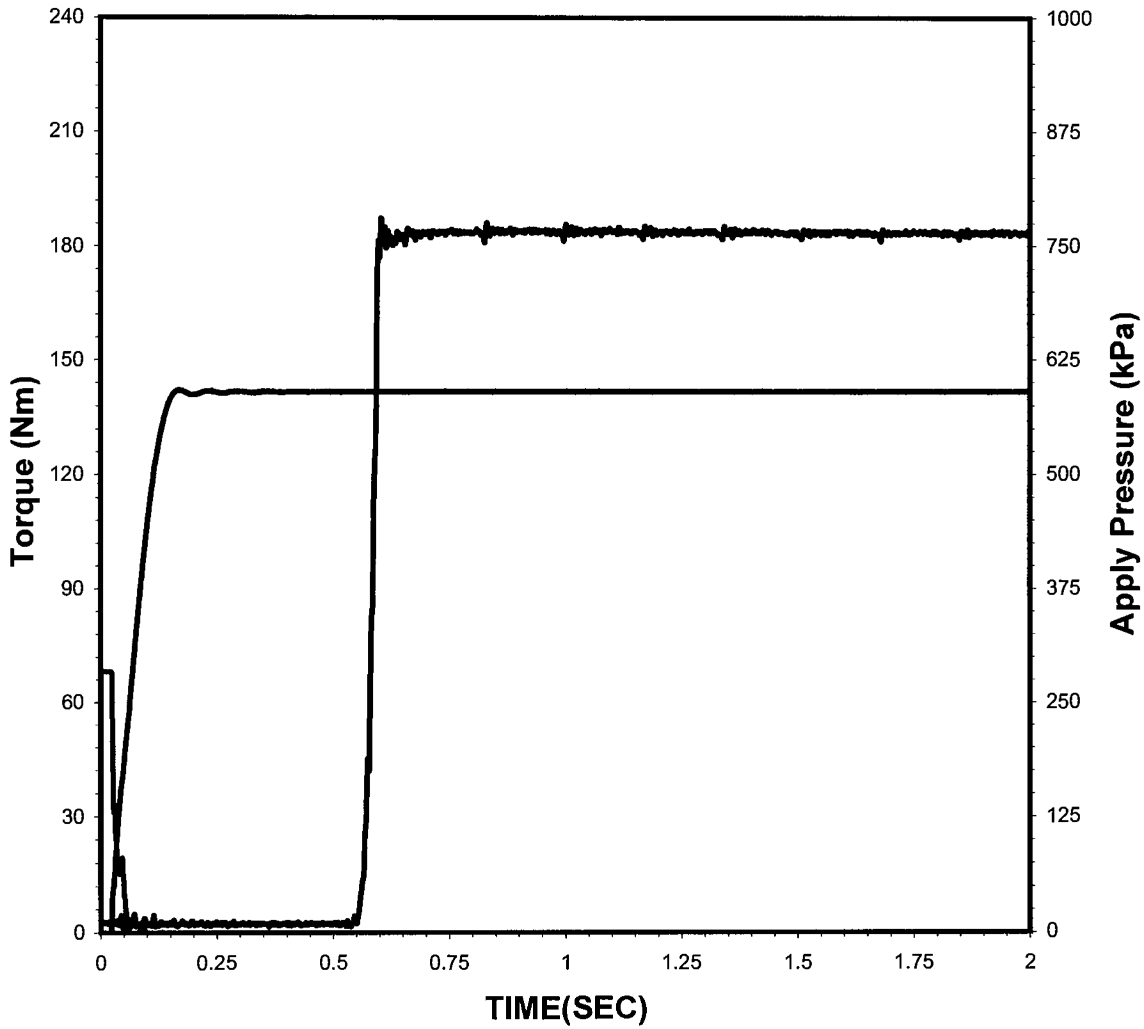
Coefficient of Friction

.2 Sec Dyn:	0.062
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.110

STATIC TRACES

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 13:24:20

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 10

PHASE A

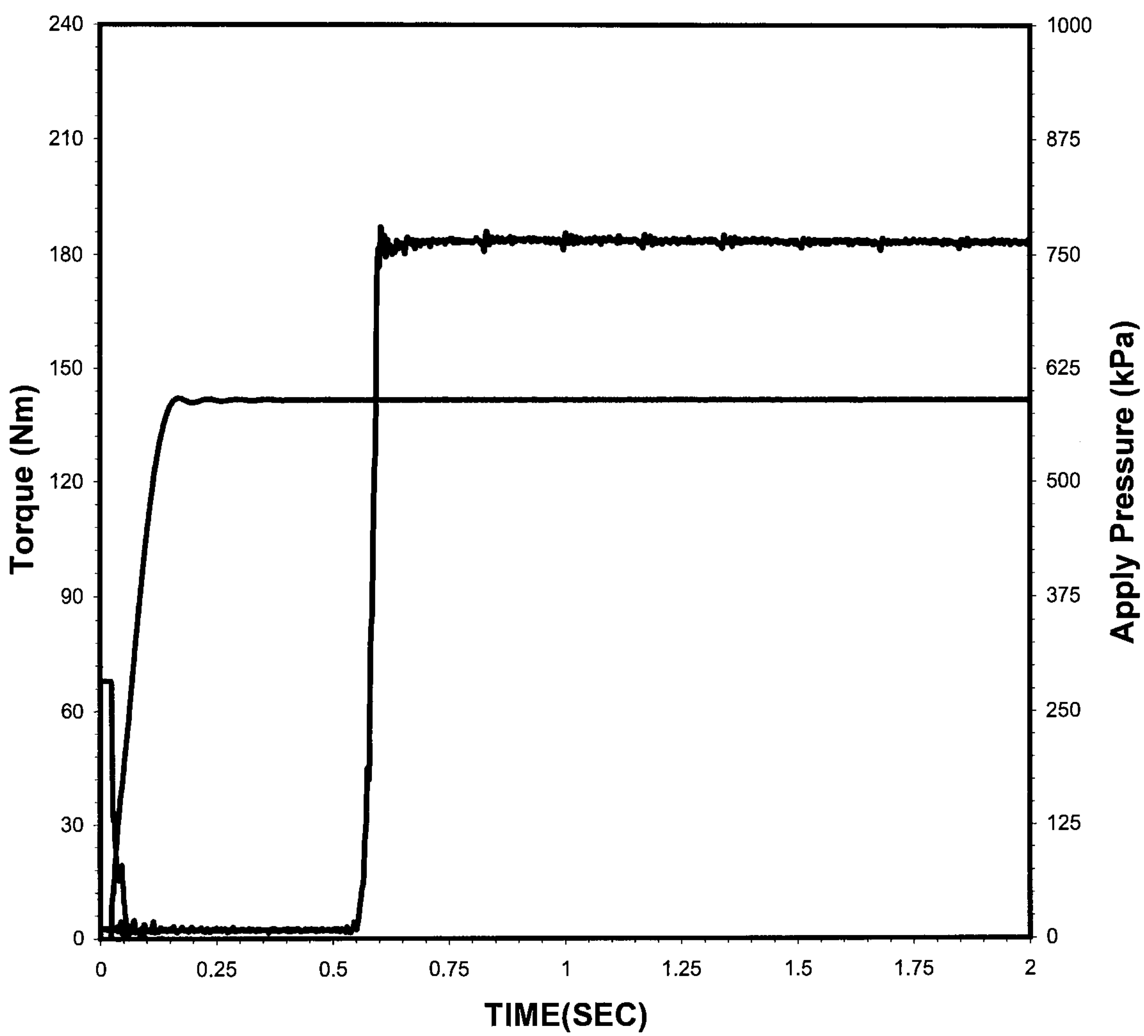
Apply Pressure:
At .25 Second: 348 kPa

Torque
Static Peak: 110 Nm
.25 Second: 83 Nm

Coefficient of Friction
Static Peak: 0.183
.25 Second: 0.137

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 15:27:02

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 500

PHASE A

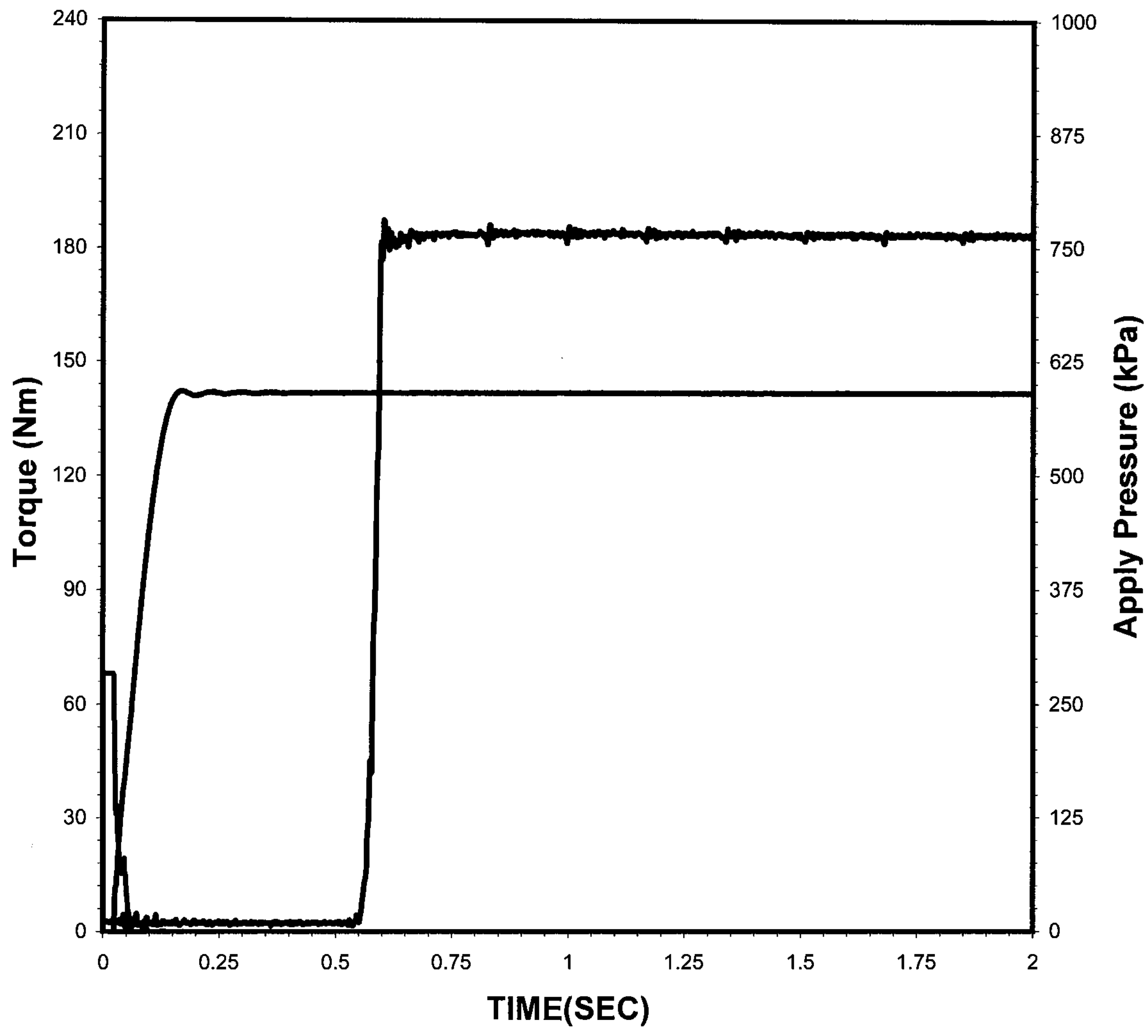
Apply Pressure:
At .25 Second: 349 kPa

Torque
Static Peak: 102 Nm
.25 Second: 82 Nm

Coefficient of Friction
Static Peak: 0.169
.25 Second: 0.136

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 17:32:13

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 1000

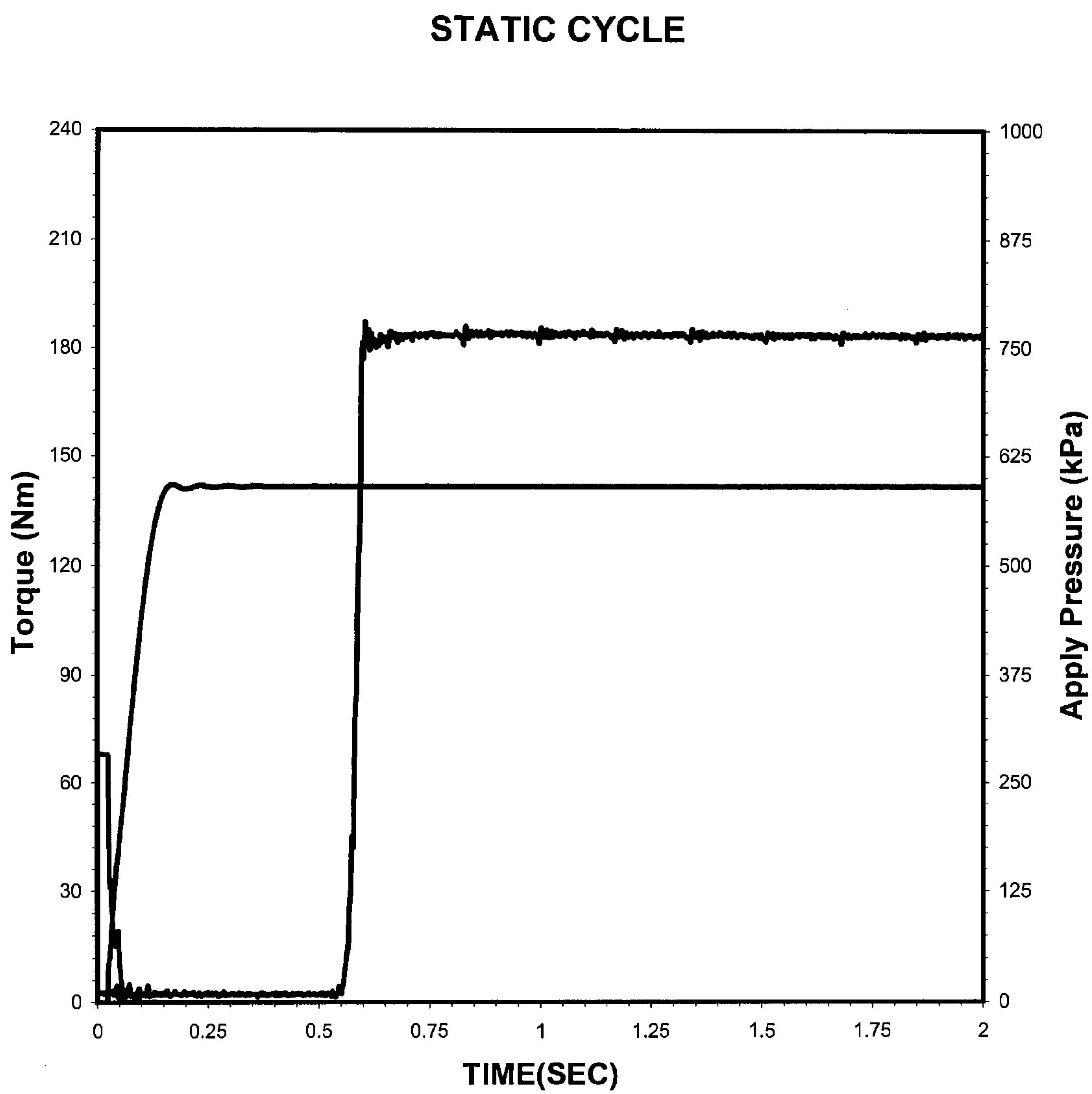
PHASE A

Apply Pressure:
At .25 Second: 350 kPa

Torque
Static Peak: 95 Nm
.25 Second: 82 Nm

Coefficient of Friction
Static Peak: 0.158
.25 Second: 0.136

ALLISON C-4 GRAPHITE DATA



Date of Test: 7/21/2010

Time of Test: 19:53:34

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 1500

PHASE B

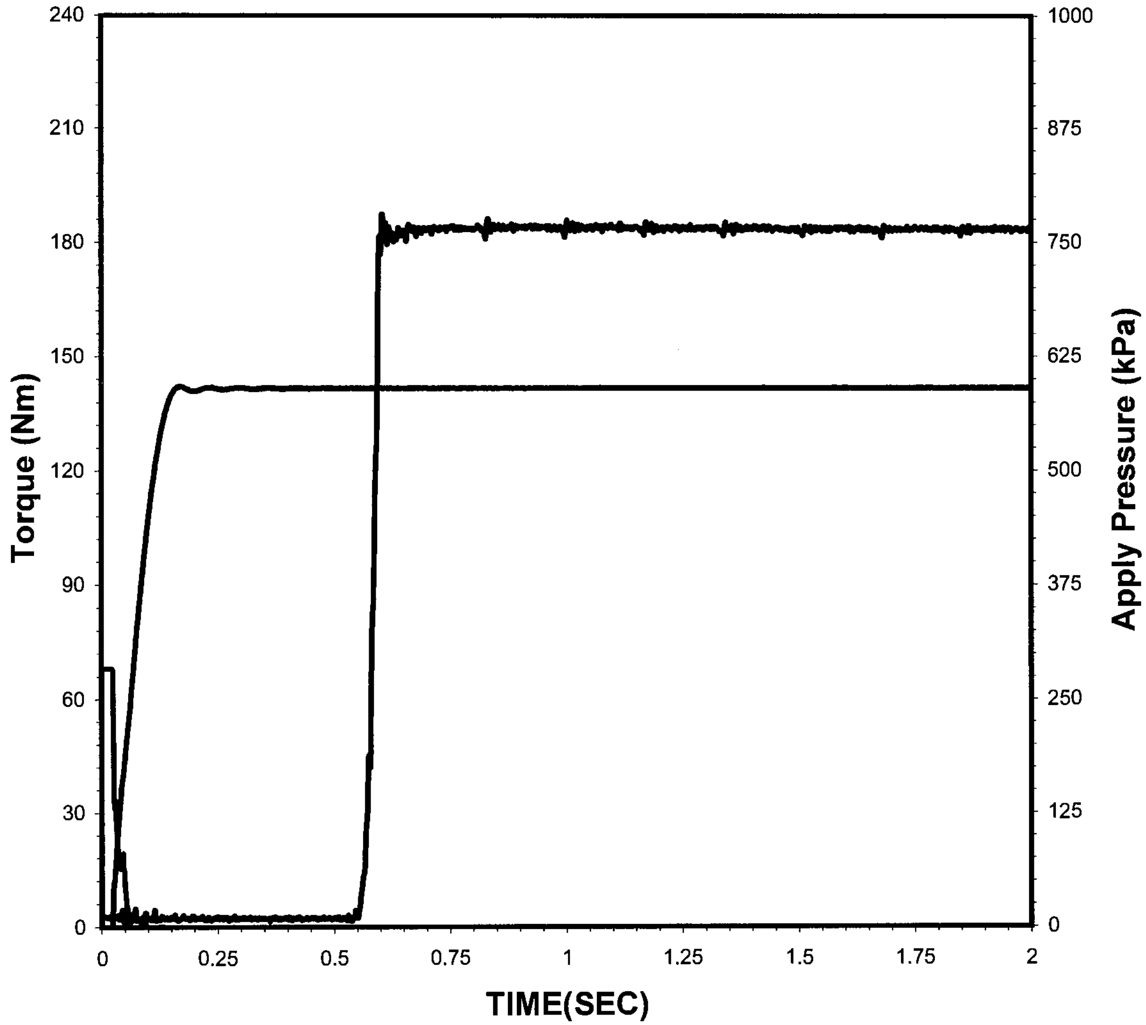
Apply Pressure:
At .25 Second: 830 kPa

Torque
Static Peak: 222 Nm
.25 Second: 188 Nm

Coefficient of Friction
Static Peak: 0.153
.25 Second: 0.130

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 21:58:46

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 2000

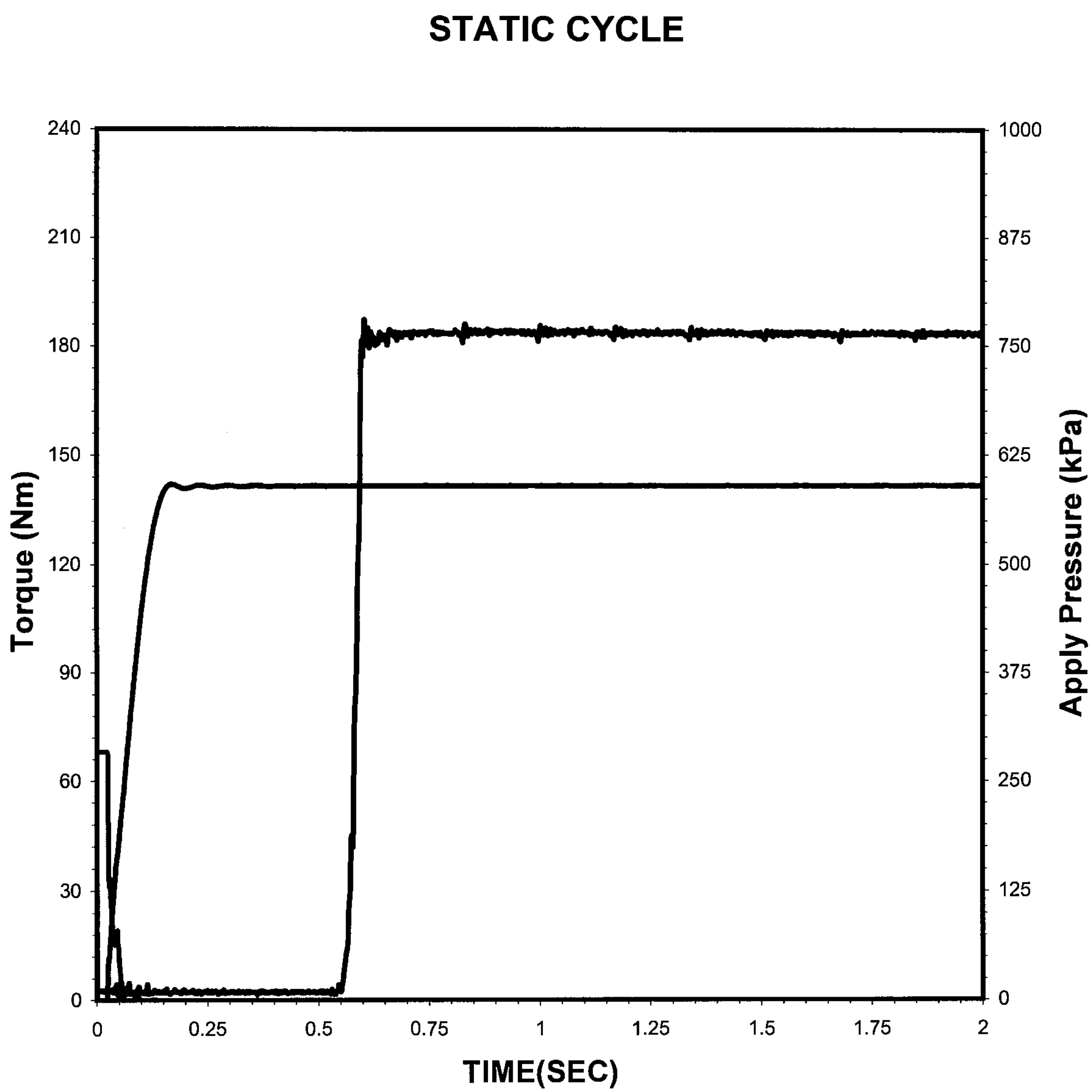
PHASE B

Apply Pressure:
At .25 Second: 830 kPa

Torque
Static Peak: 225 Nm
.25 Second: 188 Nm

Coefficient of Friction
Static Peak: 0.155
.25 Second: 0.130

ALLISON C-4 GRAPHITE DATA



Date of Test: 7/22/2010

Time of Test: 0:03:57

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 2500

PHASE B

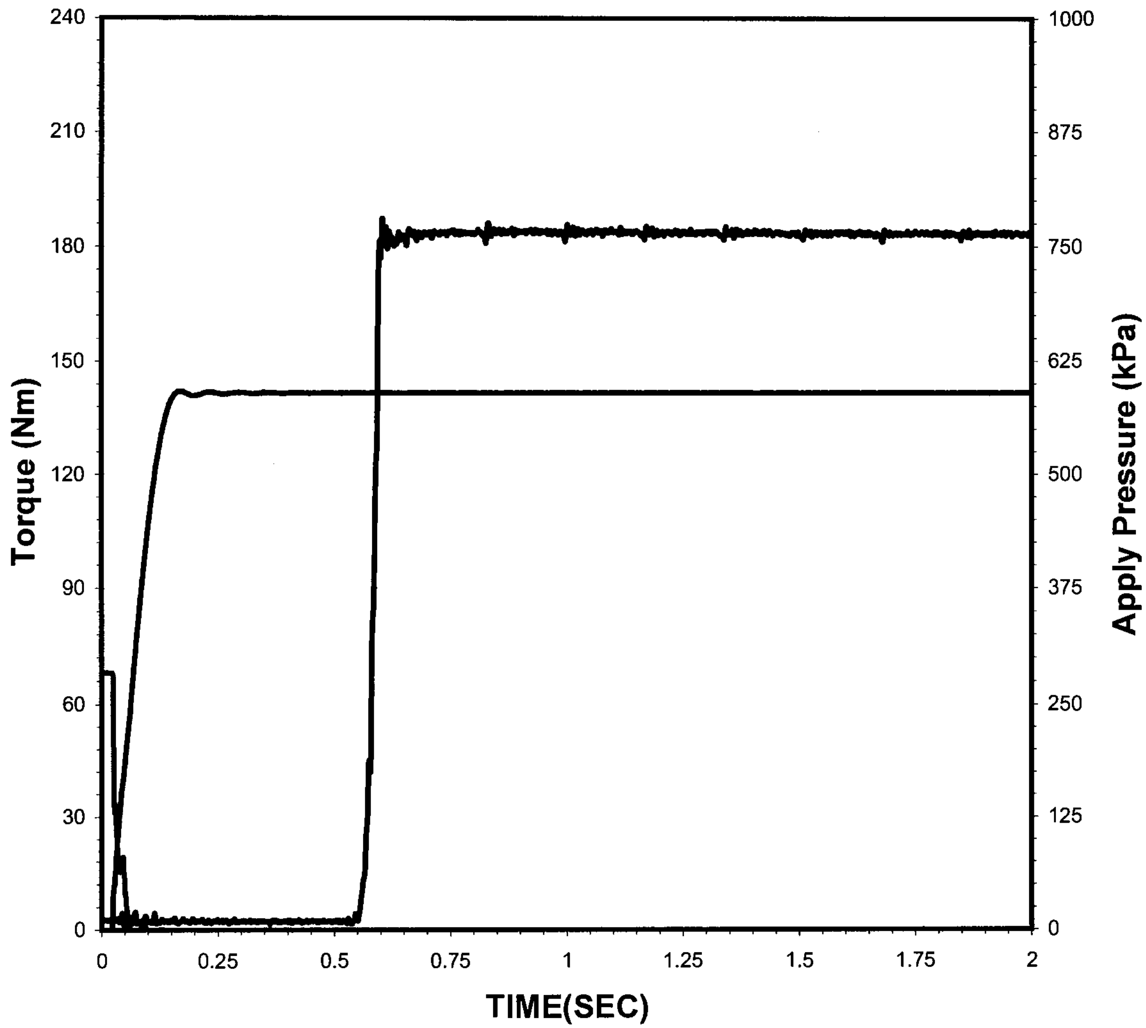
Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 215 Nm
.25 Second: 186 Nm

Coefficient of Friction
Static Peak: 0.149
.25 Second: 0.129

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 2:09:09

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 3000

PHASE B

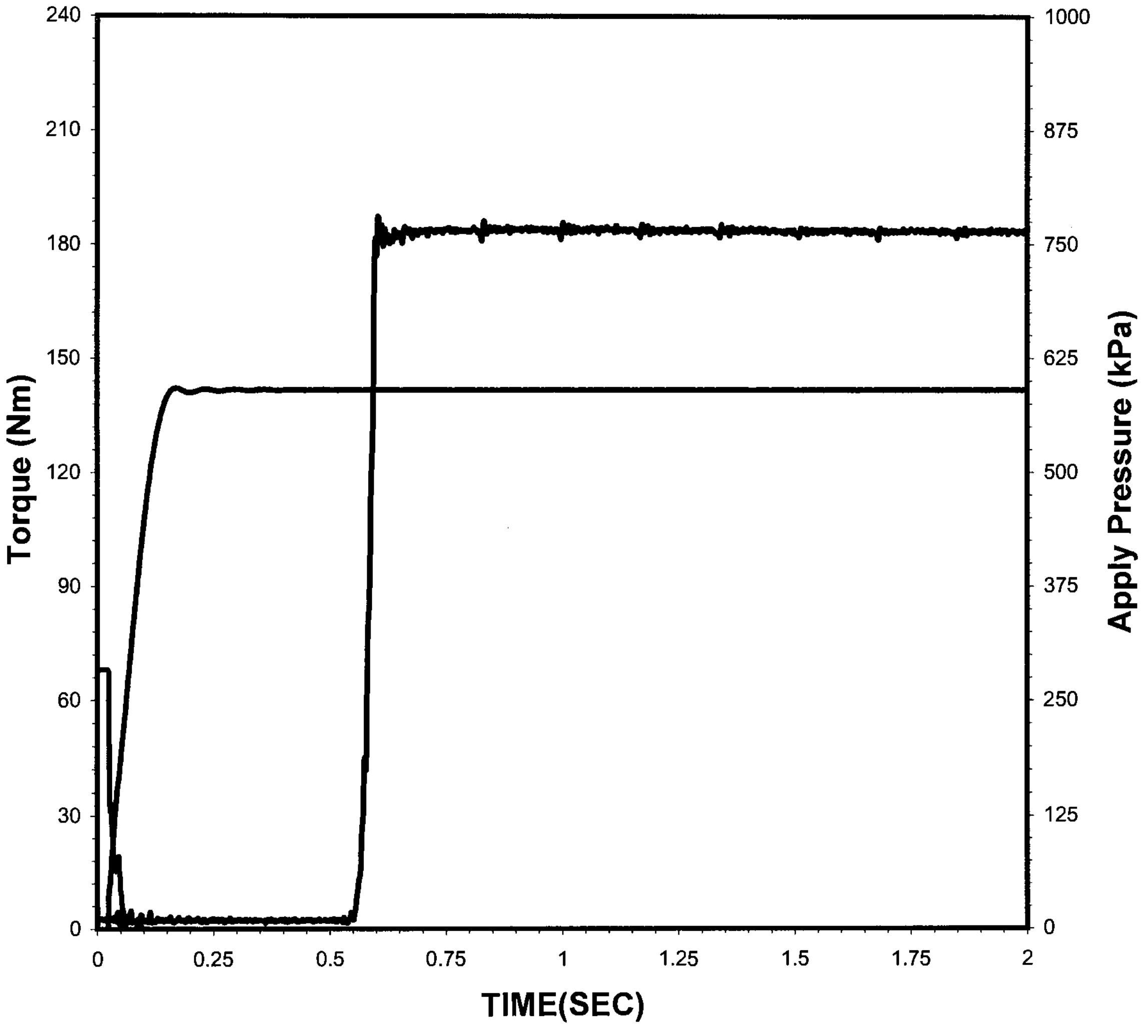
Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 212 Nm
.25 Second: 188 Nm

Coefficient of Friction
Static Peak: 0.147
.25 Second: 0.130

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 4:14:21

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 3500

PHASE B

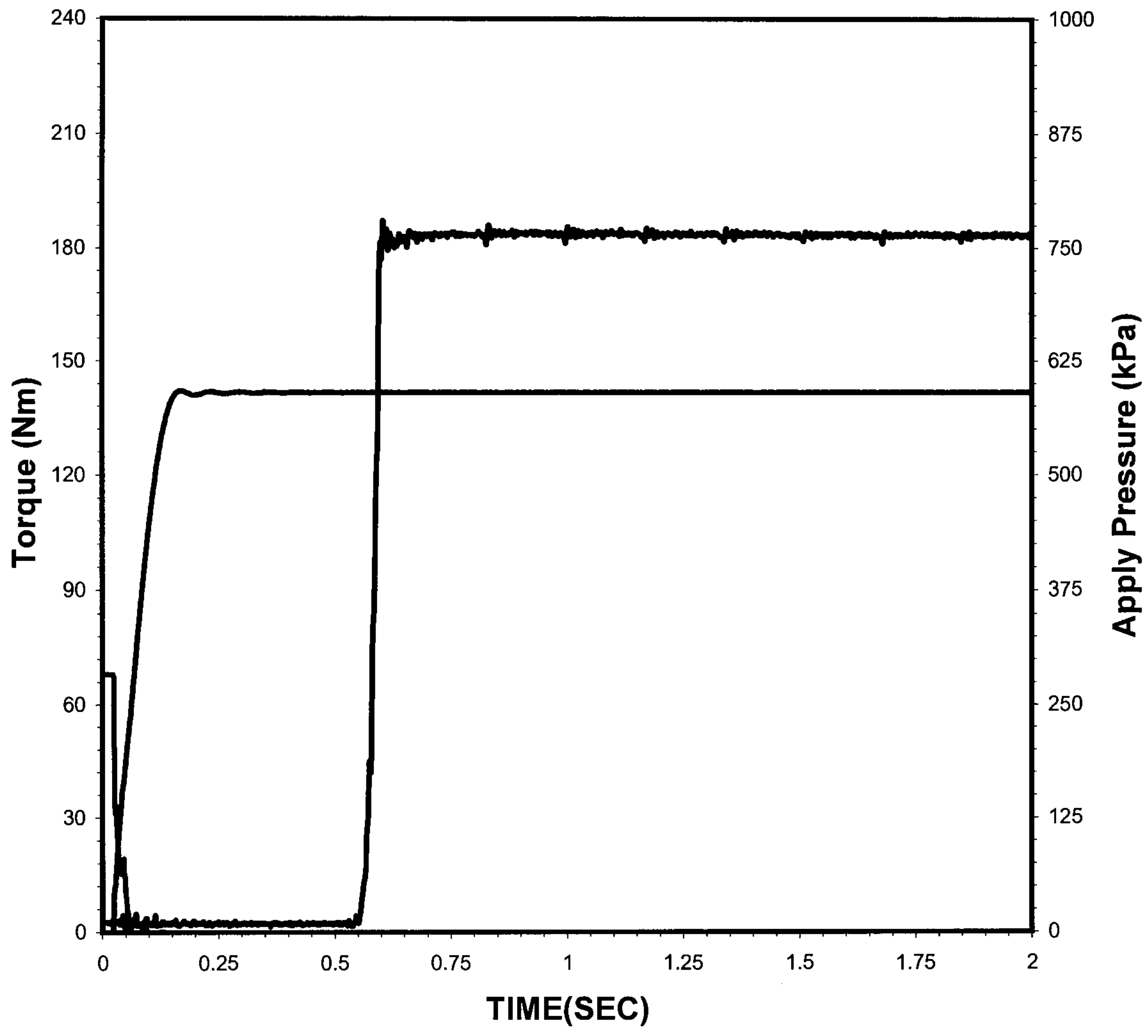
Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 198 Nm
.25 Second: 183 Nm

Coefficient of Friction
Static Peak: 0.137
.25 Second: 0.126

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 6:19:33

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 4000

PHASE B

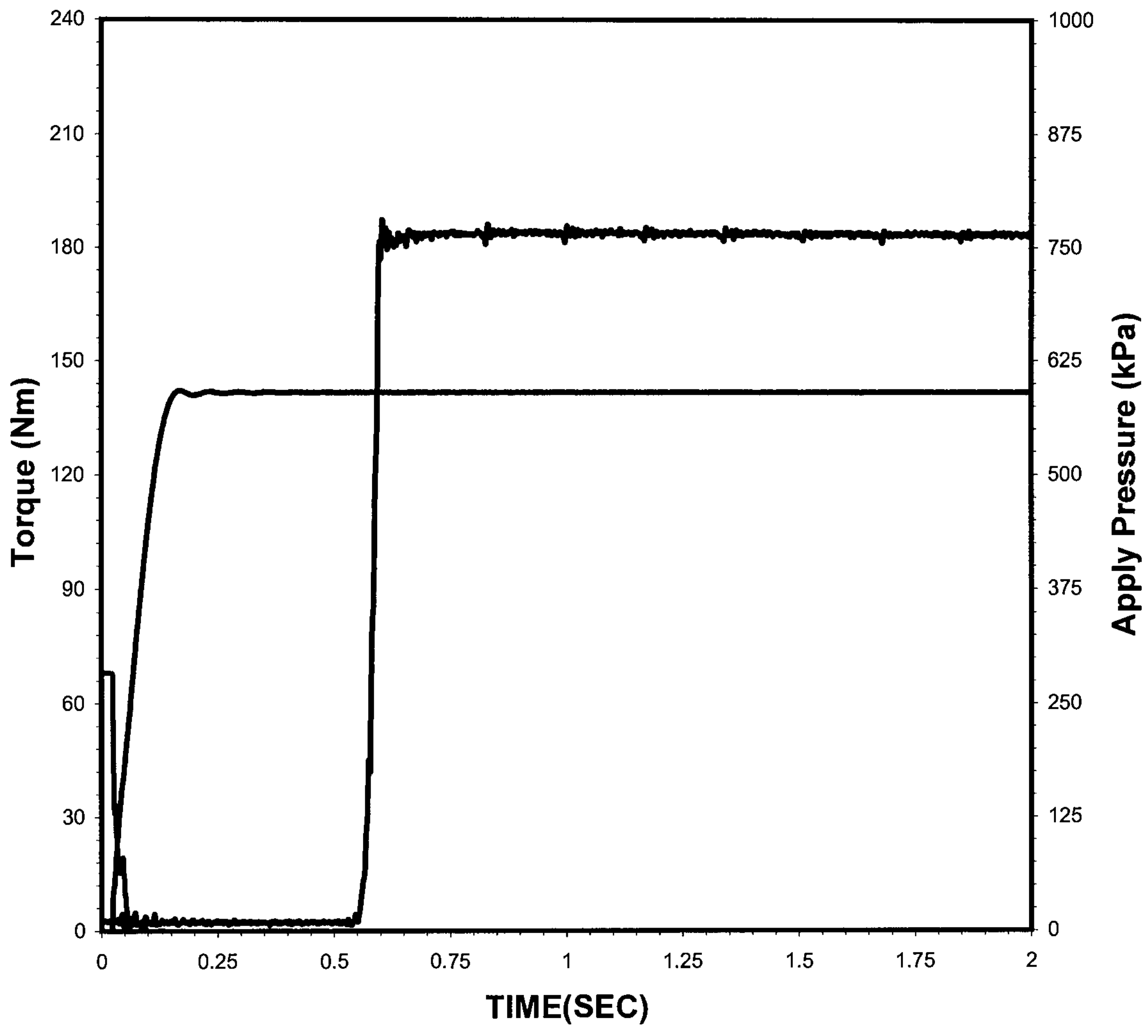
Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 206 Nm
.25 Second: 183 Nm

Coefficient of Friction
Static Peak: 0.143
.25 Second: 0.126

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 8:24:45

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 4500

PHASE B

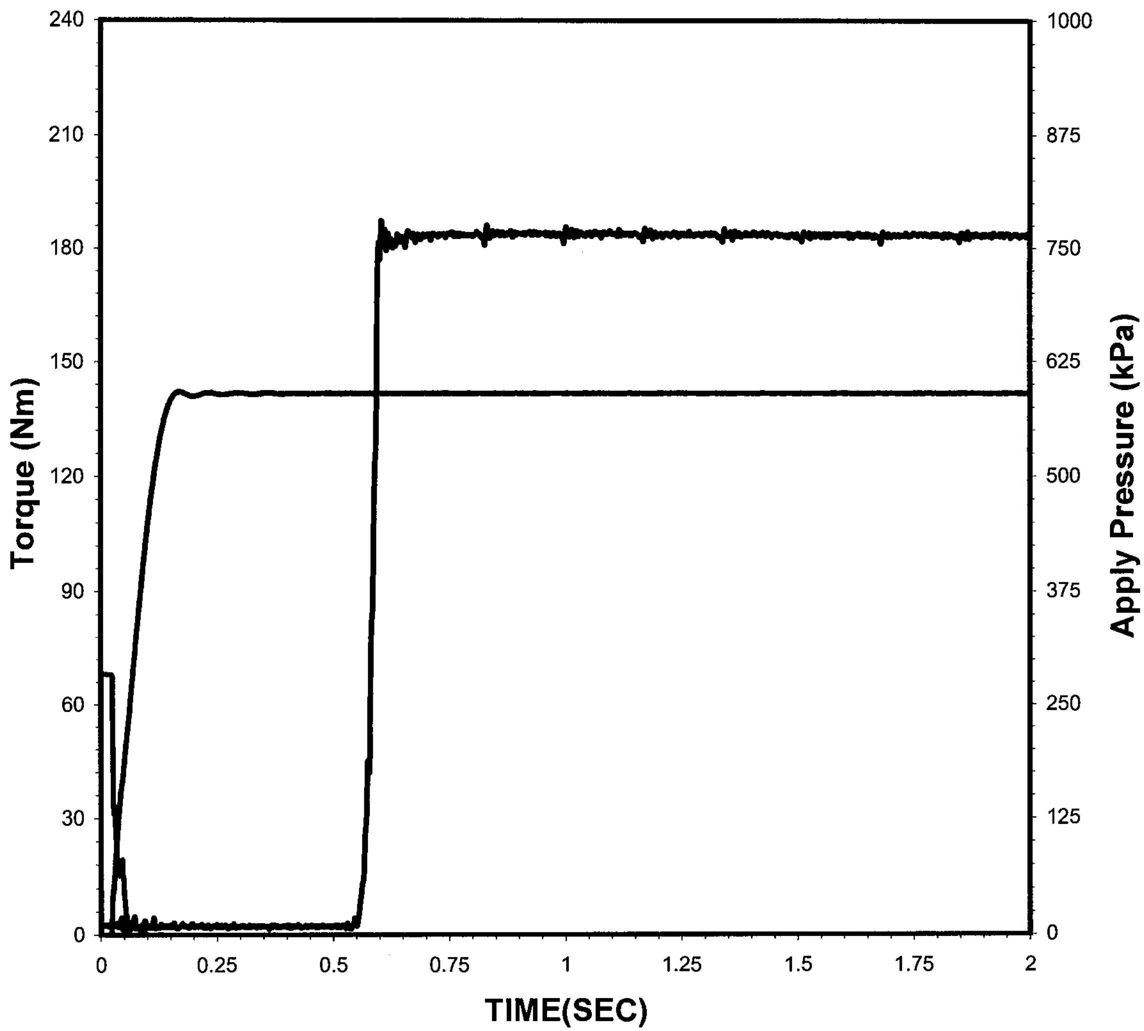
Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 207 Nm
.25 Second: 182 Nm

Coefficient of Friction
Static Peak: 0.143
.25 Second: 0.126

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 10:29:56

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 5000

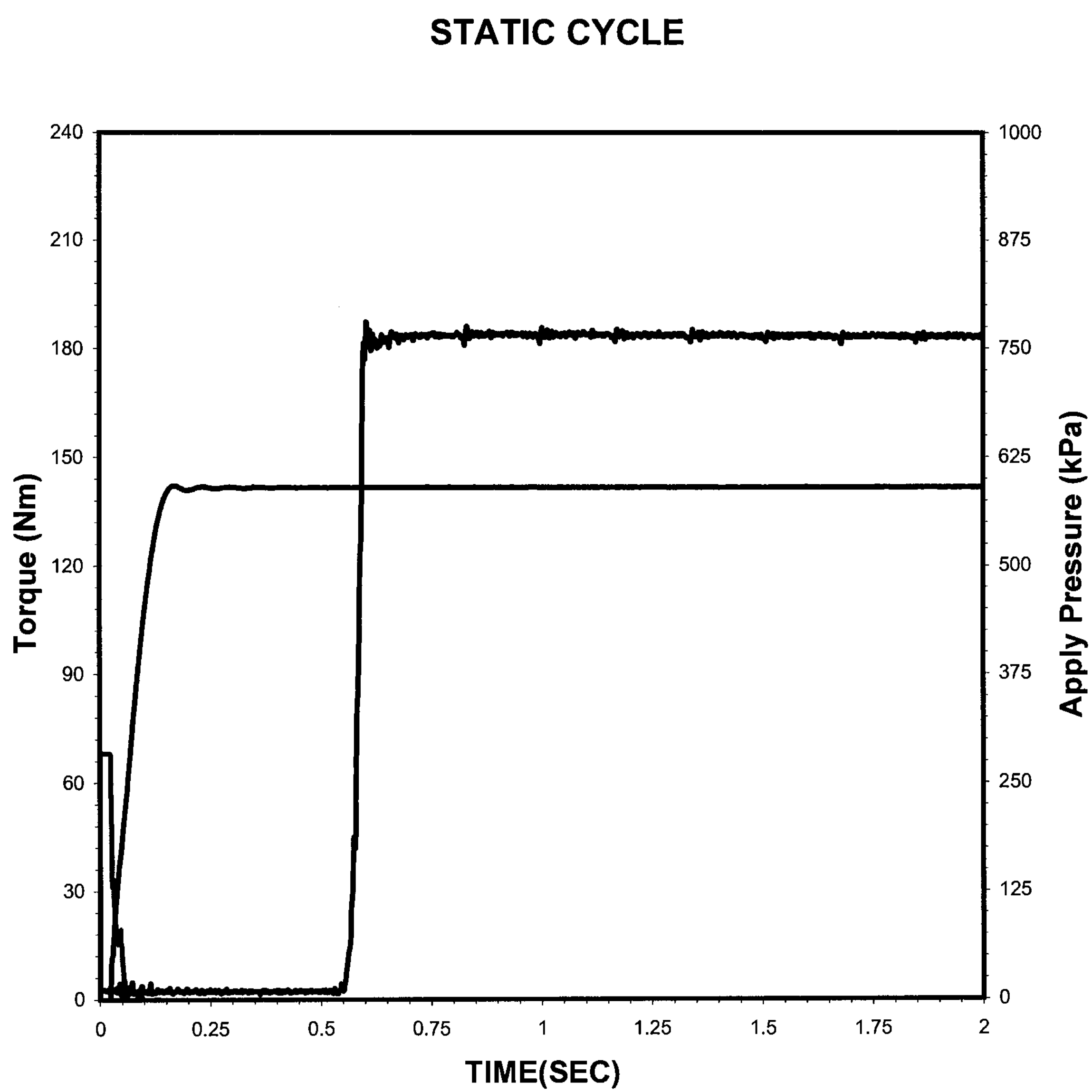
PHASE B

Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 207 Nm
.25 Second: 180 Nm

Coefficient of Friction
Static Peak: 0.143
.25 Second: 0.125

ALLISON C-4 GRAPHITE DATA



Date of Test: 7/22/2010

Time of Test: 12:35:08

Test Number: C4-8-1286

Fluid Code: LO253071

Cycle Number: 5500

PHASE B

Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 196 Nm
.25 Second: 178 Nm

Coefficient of Friction
Static Peak: 0.136
.25 Second: 0.123

End of Report

At

This Point

Remaining Documentation is Back-up

A - N/P

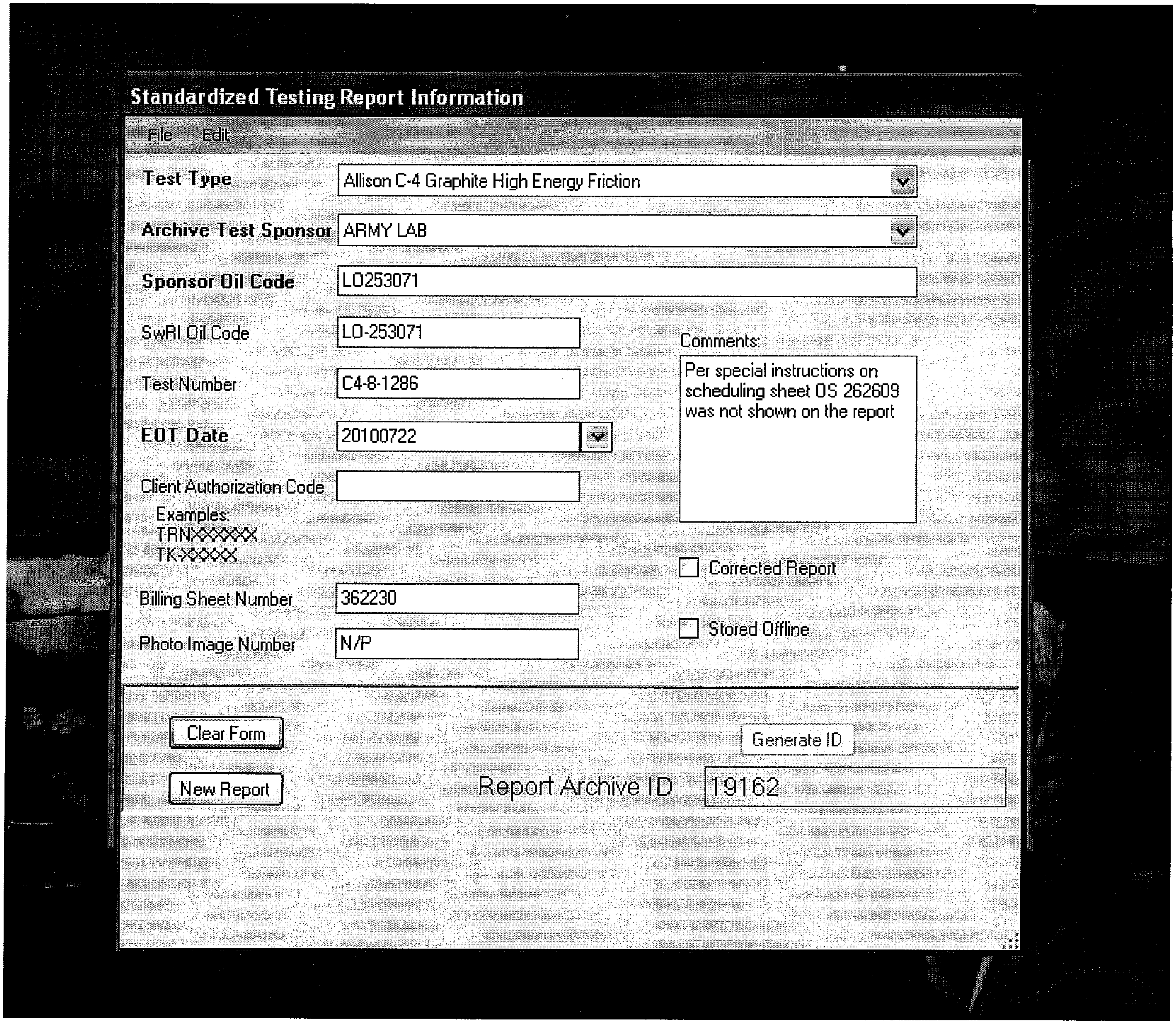
Index #: 19162

Scanned: 8/2/10 hn

Photos Merged: N/P

QA Check:

Purge JPEGs:



Standardized Testing Report Information

File Edit

Test Type	Allison C-4 Graphite High Energy Friction
Archive Test Sponsor	ARMY LAB
Sponsor Oil Code	LO253071
SwRI Oil Code	LO-253071
Test Number	C4-8-1286
EOT Date	20100722
Client Authorization Code	
Billing Sheet Number	362230
Photo Image Number	N/P

Examples:
TRNXXXXXX
TK-XXXXX

Comments:
Per special instructions on scheduling sheet OS 262609 was not shown on the report

☐ Corrected Report

☐ Stored Offline

Clear Form

New Report

Generate ID

Report Archive ID 19162

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted For

ARMY LAB

Oil Code:
LO253071

Test Number:
C2-7-1552

July 25, 2010

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

IX. Paper Clutch Friction Test

Test Laboratory: SWRI
Test Number: C2-7-1552
Friction Plate Batch: BATCH 5
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-253071
Sponsor Fluid Code: LO-253071
Completion Date: 07/25/10

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0010	0.0001
Clutch Plate	0.0900	0.0784

	Before	After
Pack Clearance	1.0414	1.3970

Reference Tests

Test Number	Test Date	Test Fluid
C2-0-1523	01/24/09	RDL-2746 08-05
C2-0-1534	11/26/09	RDL-2746 08-05
C2-0-1545	04/03/10	RDL-2746 08-05

	New	EOT
Viscosity at 40°C, cSt	43.56	38.30
Viscosity at 100°C, cSt	8.34	7.44
Iron Content, ppm	2	130

D5185	New Fluid (ppm)
Ba	<1
B	3
Ca	3565
Mg	12
P	1269
Si	6
Na	23
Zn	1875

Name: Matthew Jackson
Title: Manager

Signature: [signature]
Date: 8/3/10

ALLISON C- 4 PAPER FRICTION TEST

(Torque in N*m)

Sponsor Fluid Code:	**LO253071**	Test Number:	**C2-7-1552**
Lab Fluid Code:	**LO-253071**	Fric. Plate Batch:	**Batch 5**
Completion Date:	**07/25/2010**	Steel Plate Batch:	**10/9/2008**

TORQUE

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.54	179	330	151	355	335
500	0.48	208	339	131	356	342
1000	0.45	227	332	105	359	338
2500	0.44	235	310	75	337	315
5000	0.44	238	292	54	332	302
7500	0.45	236	267	31	292	278
10000	0.45	235	256	21	278	270

COEFFICIENT OF FRICTION

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.54	0.087	0.161	0.074	0.173	0.163
500	0.48	0.101	0.165	0.064	0.173	0.167
1000	0.45	0.111	0.162	0.051	0.175	0.165
2500	0.44	0.114	0.151	0.037	0.164	0.153
5000	0.44	0.116	0.142	0.026	0.162	0.147
7500	0.45	0.115	0.130	0.015	0.142	0.135
10000	0.45	0.114	0.125	0.011	0.135	0.131

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.540	0.450	-16.67	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.087	0.114	31.03	F
Static Friction Coeff.	N/A	N/A	0.161	0.125	-22.36	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.173	0.135	-21.97	
0.25 Second Low Speed Coeff.	N/A	N/A	0.163	0.131	-19.63	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-PAPER FRICTION TEST

(all units in mm)

Candidate Fluid: L0253071 **Test Number : C2-7-1552** **Completion Date : 7/25/2010**

Lab Fluid Code : LO-253071 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 5**

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.0450	1.9560	2.0320	1.9560	0.0890		0.0760
	120	2.0350	1.9540	2.0270	1.9580	0.0810		0.0690
	240	2.0310	1.9480	2.0250	1.9550	0.0830		0.0700
	Average					0.0843	0.0780	0.0717
5	Top	2.0520	1.9680	2.0410	1.9710	0.0840		0.0700
	120	2.0530	1.9630	2.0530	1.9740	0.0900		0.0790
	240	2.0460	1.9660	2.0410	1.9720	0.0800		0.0690
	Average					0.0847	0.0787	0.0727
STEELS SEPARATORS								
1	Top	1.7530	1.7530	1.7530	1.7530	0.0000		0.0000
	120	1.7530	1.7530	1.7530	1.7530	0.0000		0.0000
	240	1.7520	1.7520	1.7530	1.7530	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7590	1.7590	1.7610	1.7610	0.0000		0.0000
	120	1.7590	1.7590	1.7580	1.7580	0.0000		0.0000
	240	1.7590	1.7590	1.7590	1.7580	0.0000		0.0010
	Average					0.0000	0.0002	0.0003
4	Top	1.7490	1.7490	1.7480	1.7480	0.0000		0.0000
	120	1.7480	1.7480	1.7490	1.7490	0.0000		0.0000
	240	1.7480	1.7480	1.7480	1.7480	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
6	Top	1.7580	1.7570	1.7590	1.7580	0.0010		0.0010
	120	1.7580	1.7580	1.7580	1.7580	0.0000		0.0000
	240	1.7590	1.7590	1.7590	1.7590	0.0000		0.0000
	Average					0.0003	0.0003	0.0003

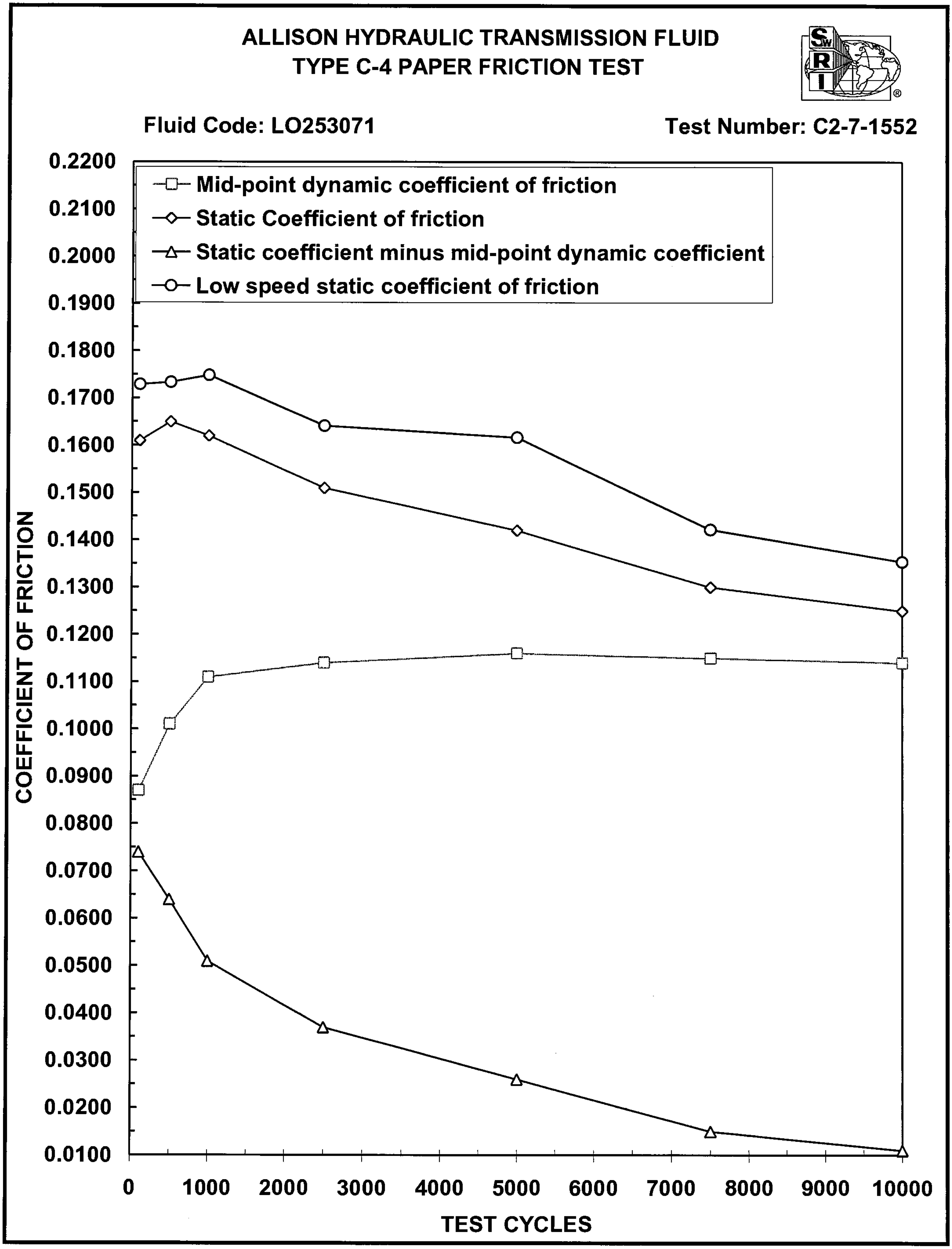
PLATE CONDITION AT E.O.T.: PLATES IN GOOD CONDITION WITH NO UNUSUAL DISCOLORATION. MICROMETER
(Anything Unusual) #0153667

Test Date and Operator's Name: 7/25/2010 MARK HOLMES

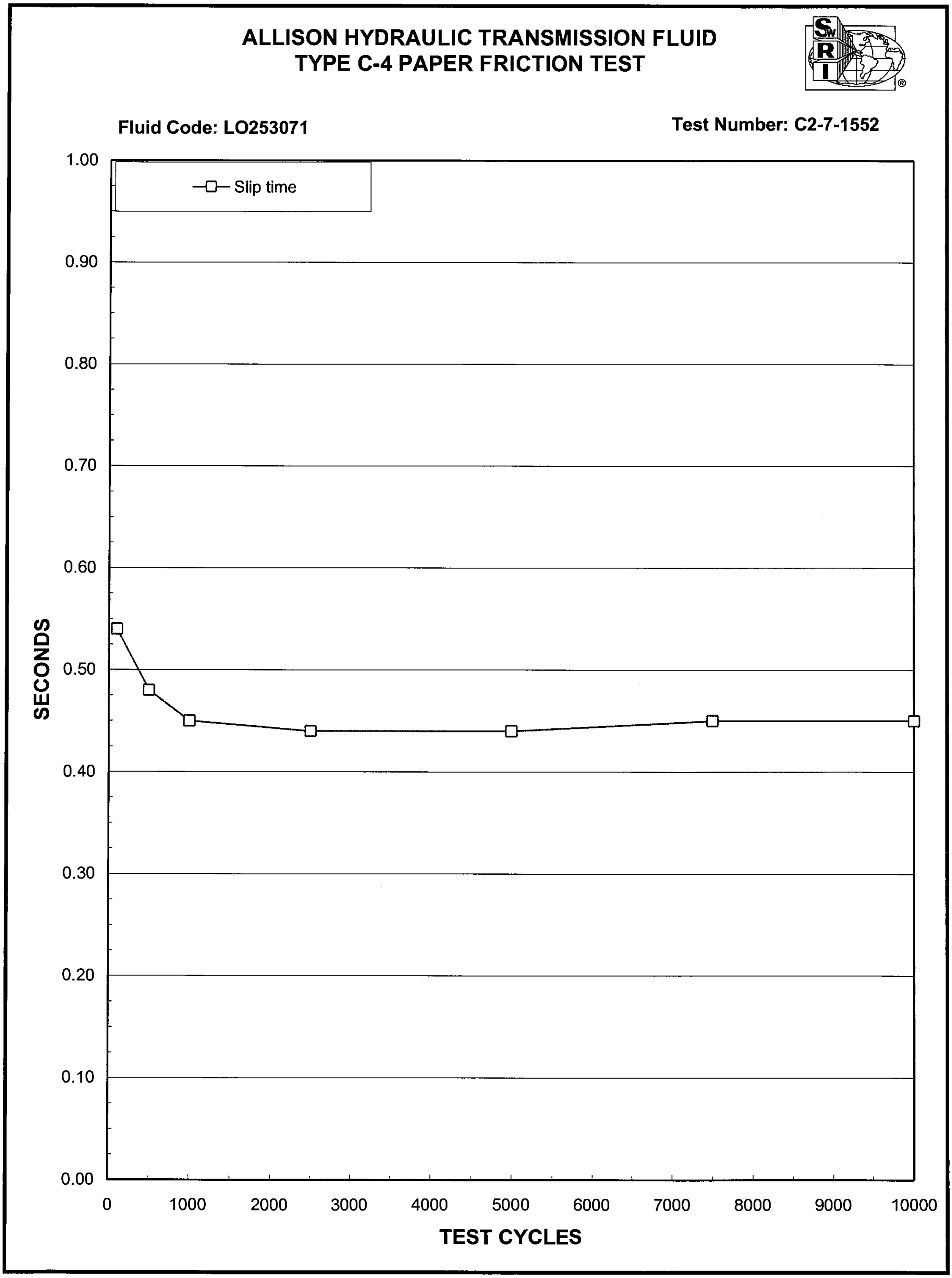
Reviewed By (Signature and Date)

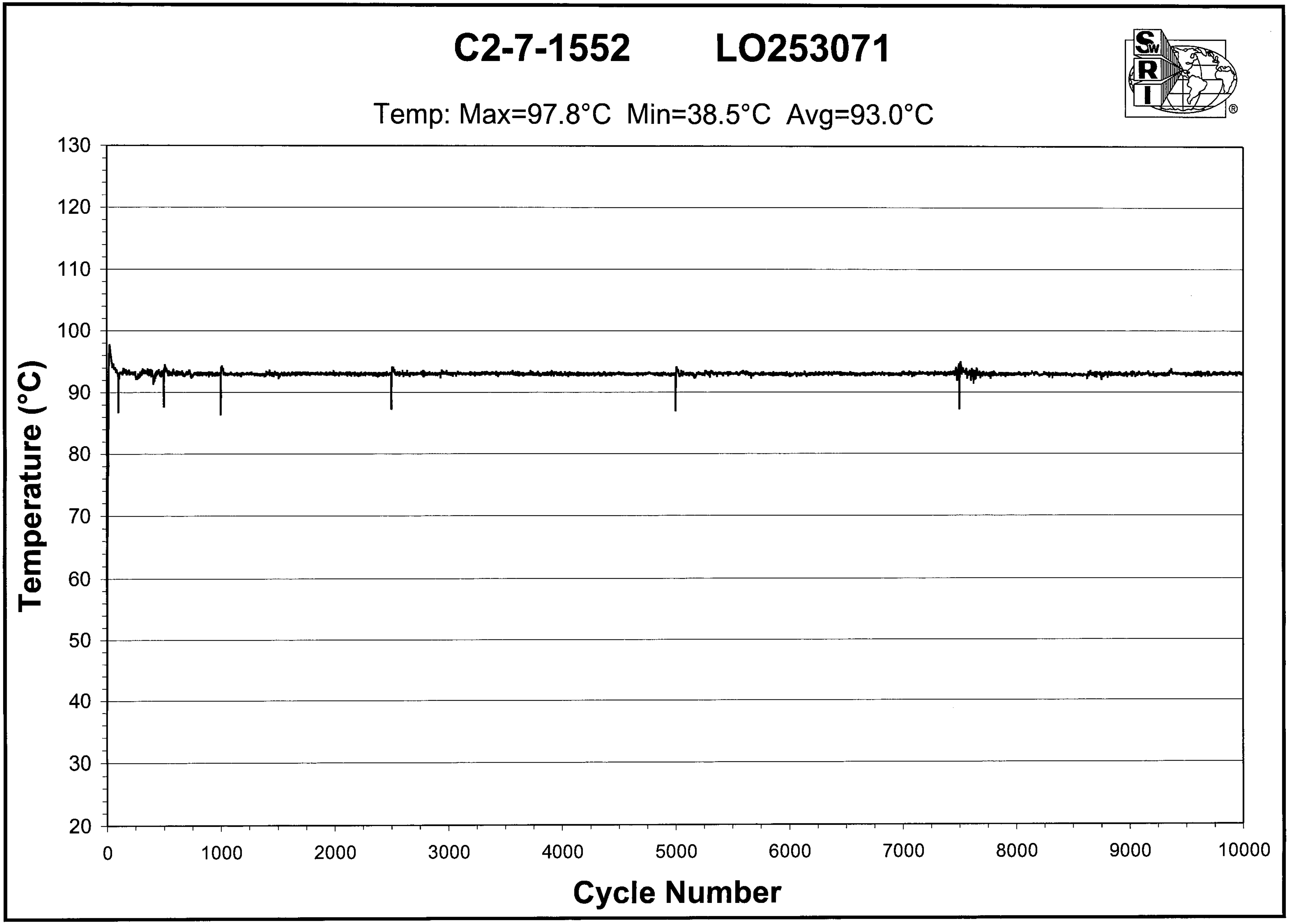
8/13/10

Pack ID#: 4411



ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO253071
Test Number: C2-7-1552
Mid-point dynamic coefficient of friction
Static Coefficient of friction
Static coefficient minus mid-point dynamic coefficient
Low speed static coefficient of friction
COEFFICIENT OF FRICTION
0.2200
0.2100
0.2000
0.1900
0.1800
0.1700
0.1600
0.1500
0.1400
0.1300
0.1200
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
TEST CYCLES

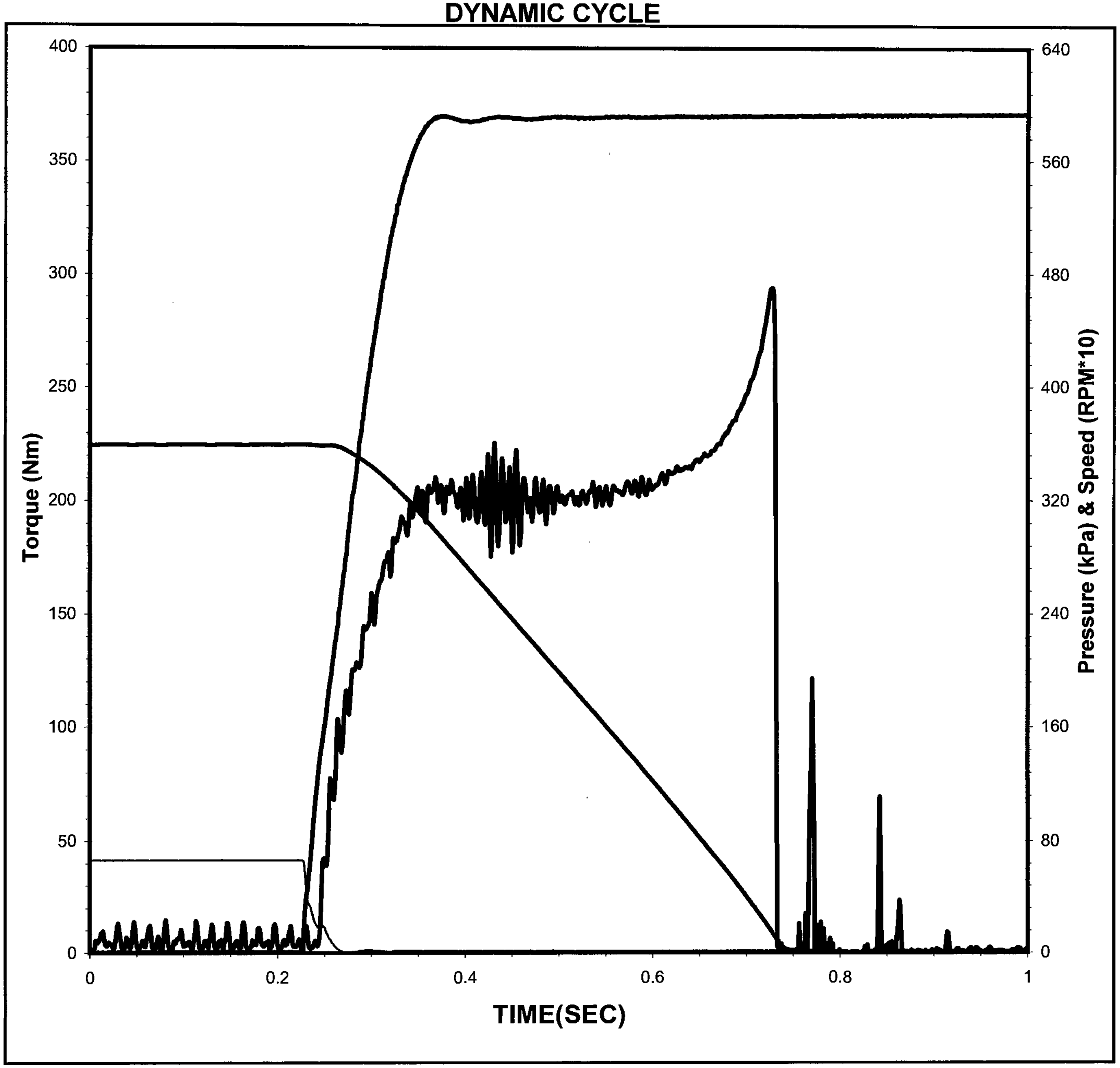

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO253071
Test Number: C2-7-1552
Slip time
SECONDS
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
TEST CYCLES



C2-7-1552 LO253071
Temp: Max=97.8°C Min=38.5°C Avg=93.0°C
130
120
110
100
90
80
70
60
50
40
30
20
Temperature (°C)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cycle Number

DYNAMIC TRACES

ALLISON C-4 PAPER DATA



Date of Test:	7/23/2010
Time of Test:	8:32:16
Test Number:	C2-7-1552
Fluid Code:	LO253071
Cycle Number:	10
Temperature:	79.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.506 Sec

Torque

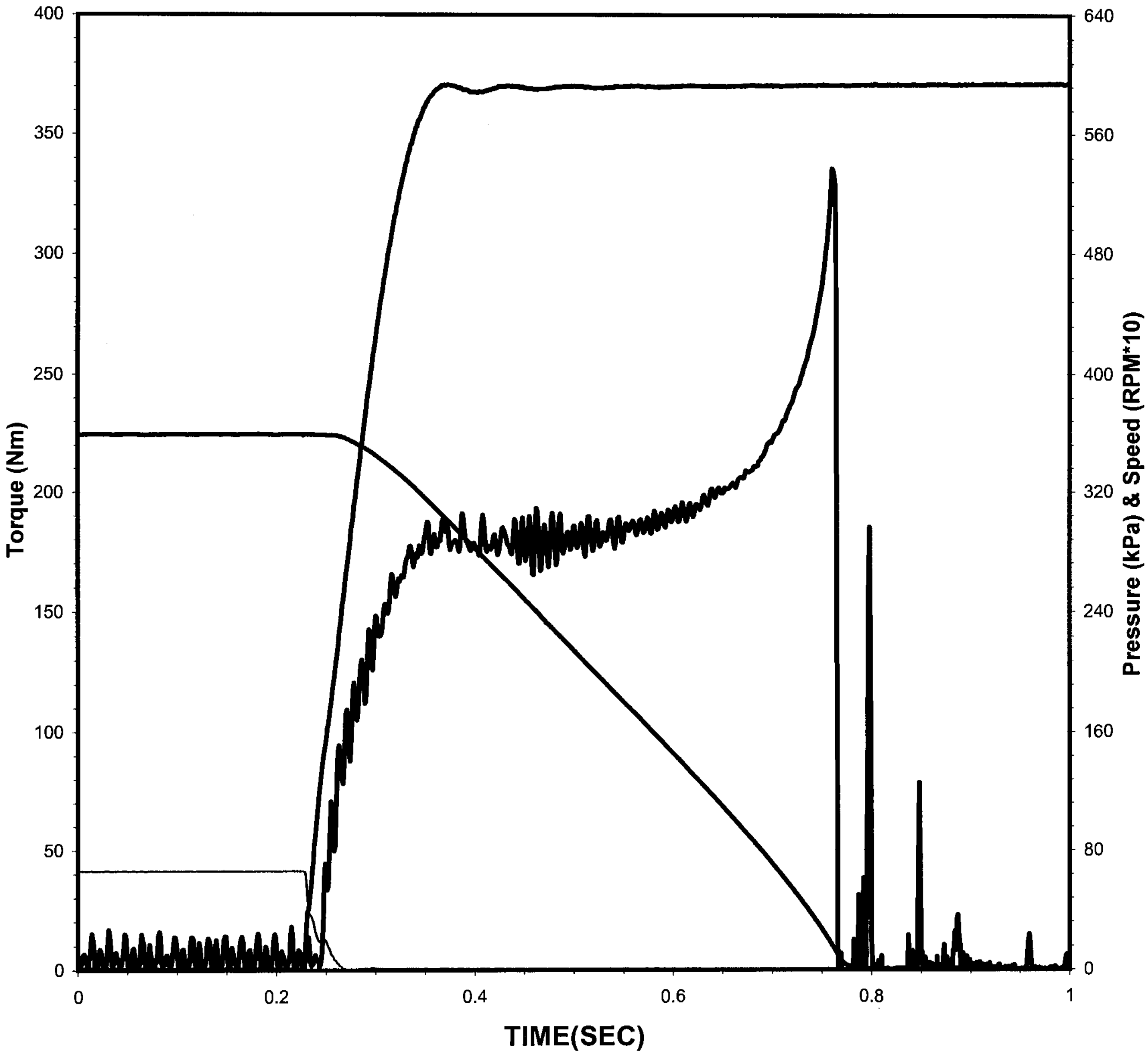
0.2 Sec Dyn:	198 N*m
Midpoint Dyn:	198 N*m
LwSpd Dynamic:	289 N*m

Coefficient of Friction

.2 Sec Dyn:	0.096
Midpoint Dyn:	0.097
LwSpd Dynamic:	0.141

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/23/2010
Time of Test:	8:54:47
Test Number:	C2-7-1552
Fluid Code:	LO253071
Cycle Number:	99
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	591 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.537 Sec

Torque

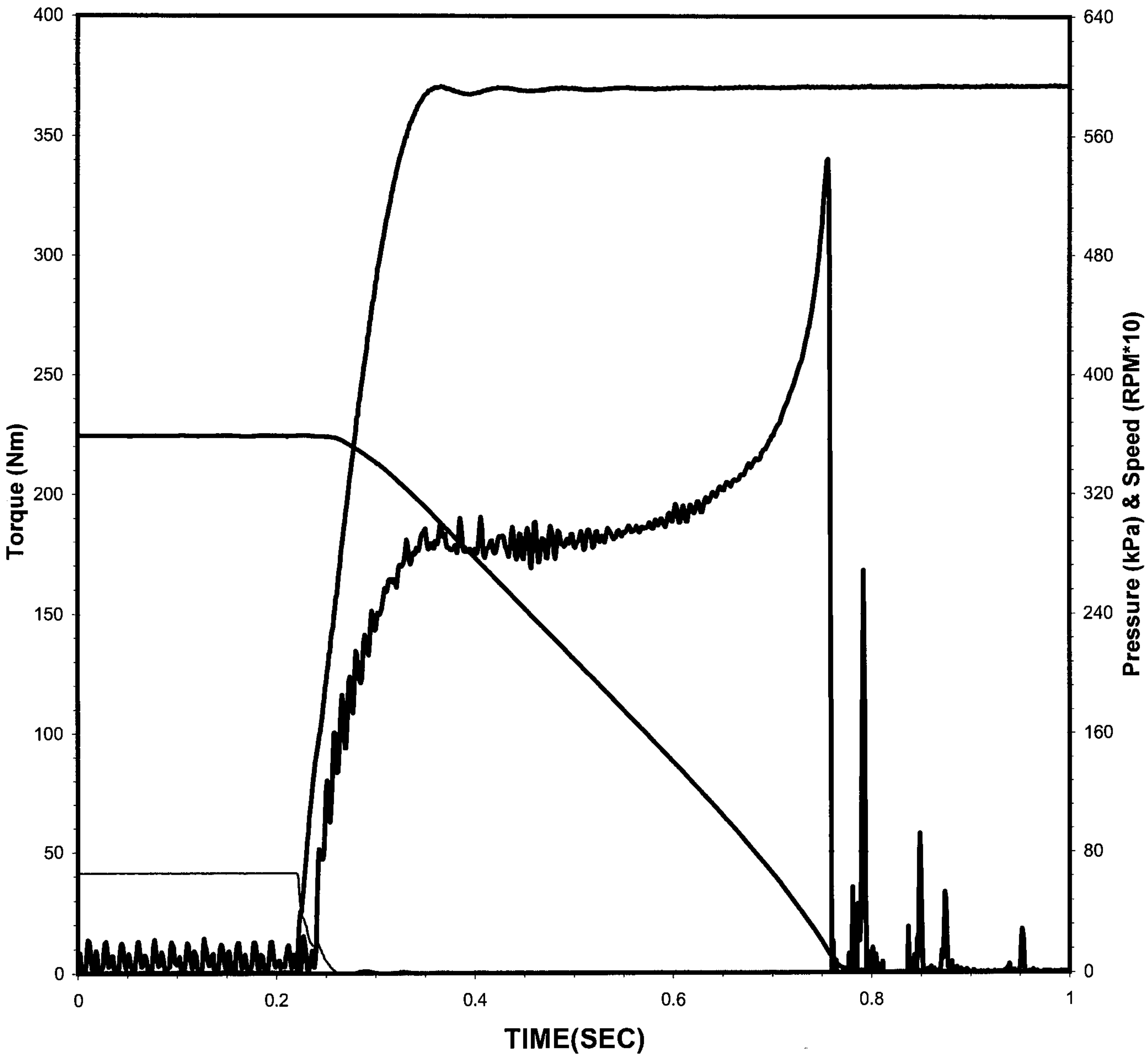
0.2 Sec Dyn:	177 N*m
Midpoint Dyn:	179 N*m
LwSpd Dynamic:	327 N*m

Coefficient of Friction

.2 Sec Dyn:	0.086
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.159

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/23/2010

Time of Test: 8:55:02

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 100

Temperature: 92.7 °C
(93.3 ± 3.0 °C)

Apply Pressure: 591 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.538 Sec

Torque

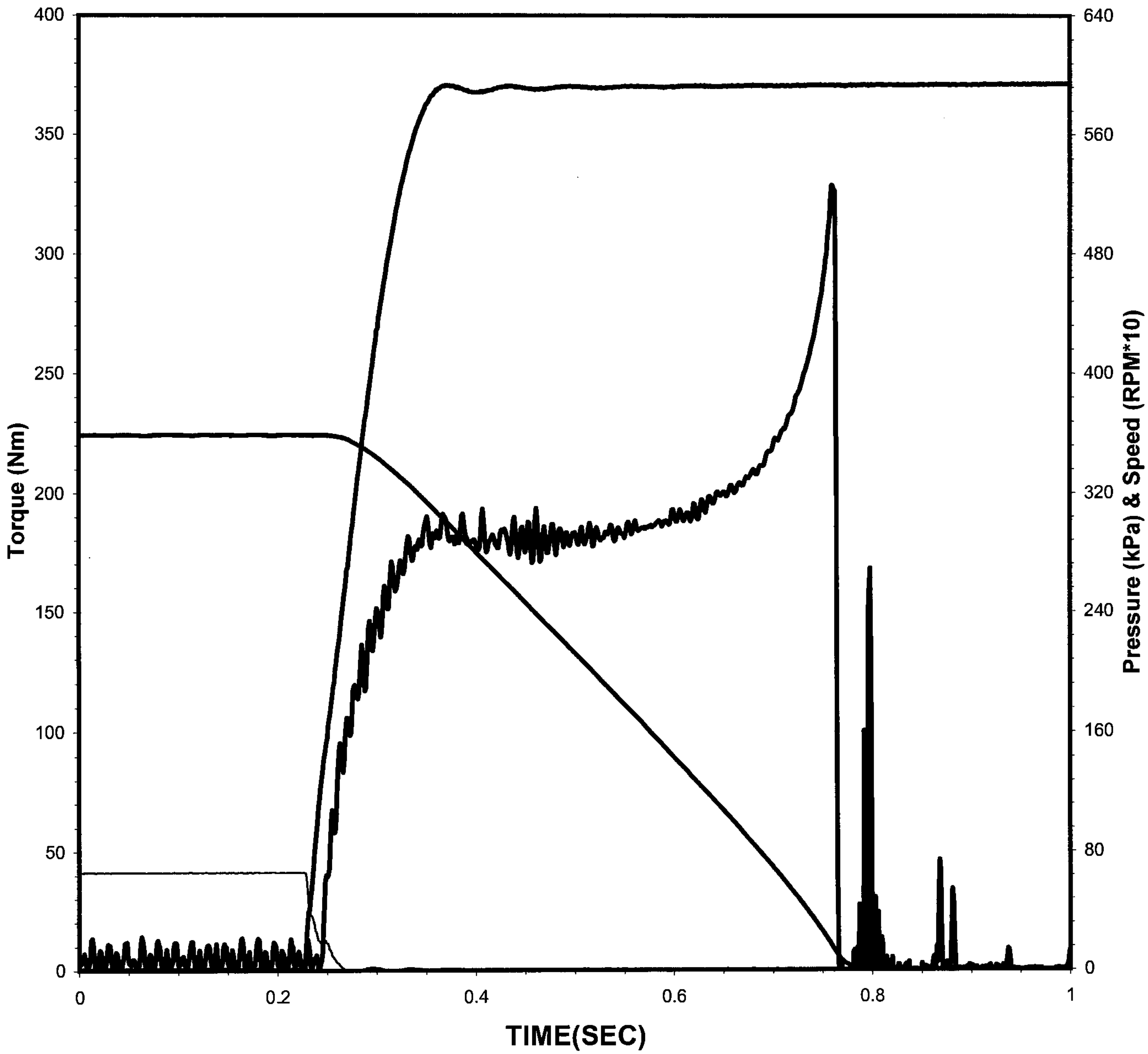
0.2 Sec Dyn:	178 N*m
Midpoint Dyn:	178 N*m
LwSpd Dynamic:	339 N*m

Coefficient of Friction

.2 Sec Dyn:	0.087
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.165

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/23/2010

Time of Test: 8:55:33

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 101

Temperature: 86.7 °C
(93.3 ± 3.0 °C)

Apply Pressure: 591 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.5 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.537 Sec

Torque

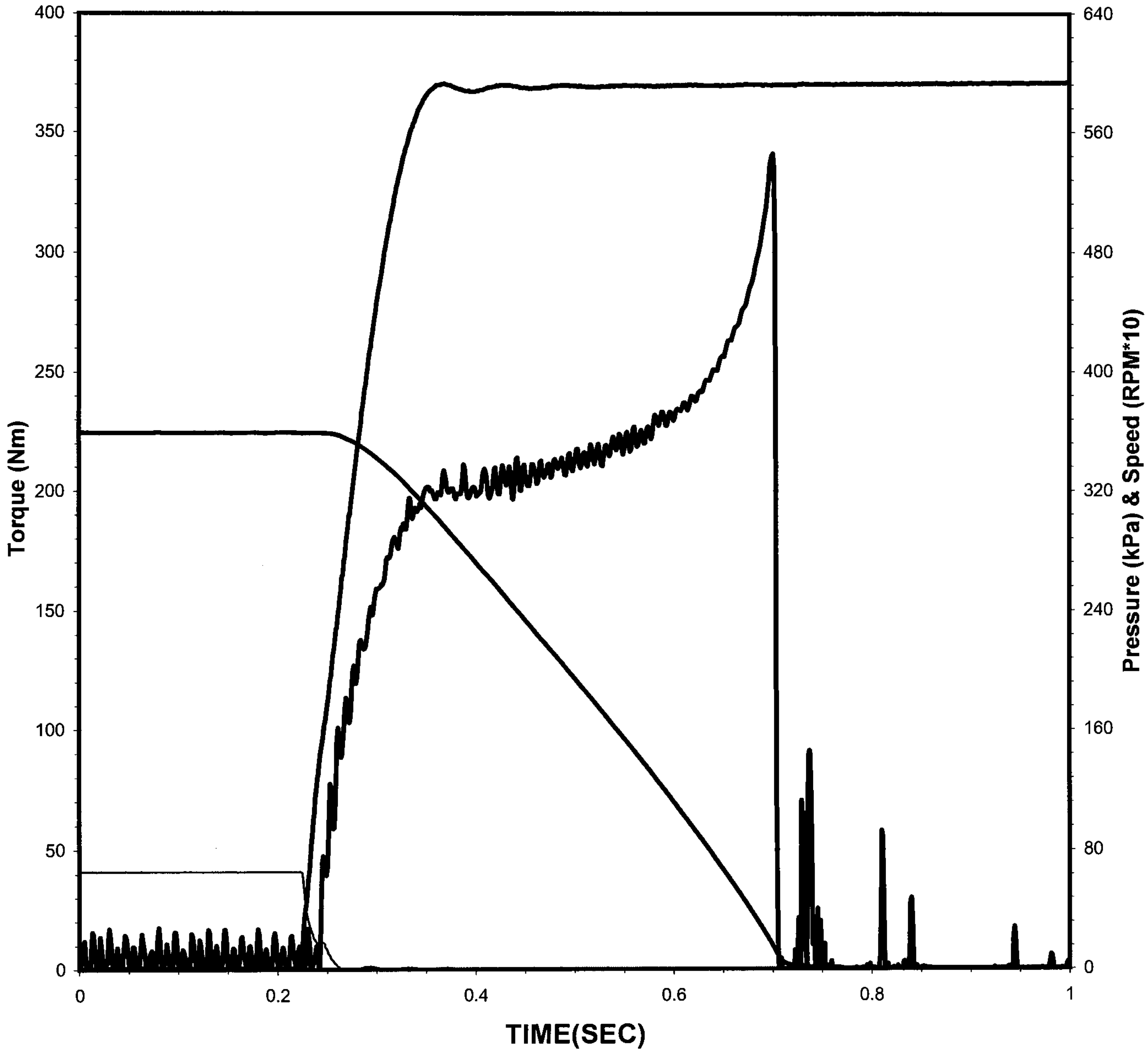
0.2 Sec Dyn: 180 N*m
Midpoint Dyn: 180 N*m
LwSpd Dynamic: 325 N*m

Coefficient of Friction

.2 Sec Dyn: 0.087
Midpoint Dyn: 0.088
LwSpd Dynamic: 0.158

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/23/2010

Time of Test: 10:35:03

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 499

Temperature: 93.7 °C
(93.3 ± 3.0 °C)

Apply Pressure: 589 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.5 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.481 Sec

Torque

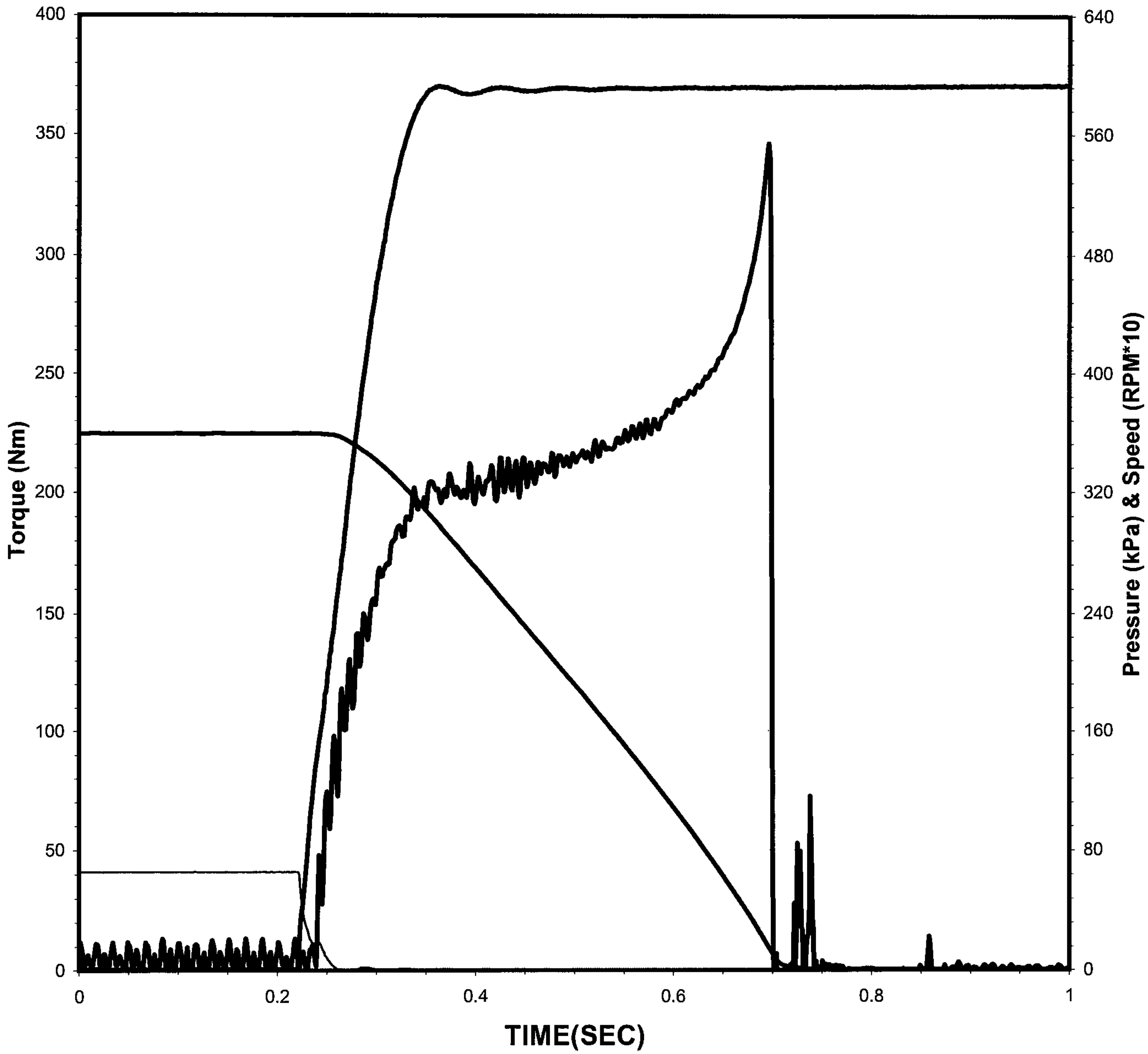
0.2 Sec Dyn:	205 N*m
Midpoint Dyn:	207 N*m
LwSpd Dynamic:	336 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.101
LwSpd Dynamic:	0.163

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/23/2010**
Time of Test:	**10:35:19**
Test Number:	**C2-7-1552**
Fluid Code:	**LO253071**
Cycle Number:	**500**
Temperature:	**93.6 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**589 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.5 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.479 Sec**

Torque

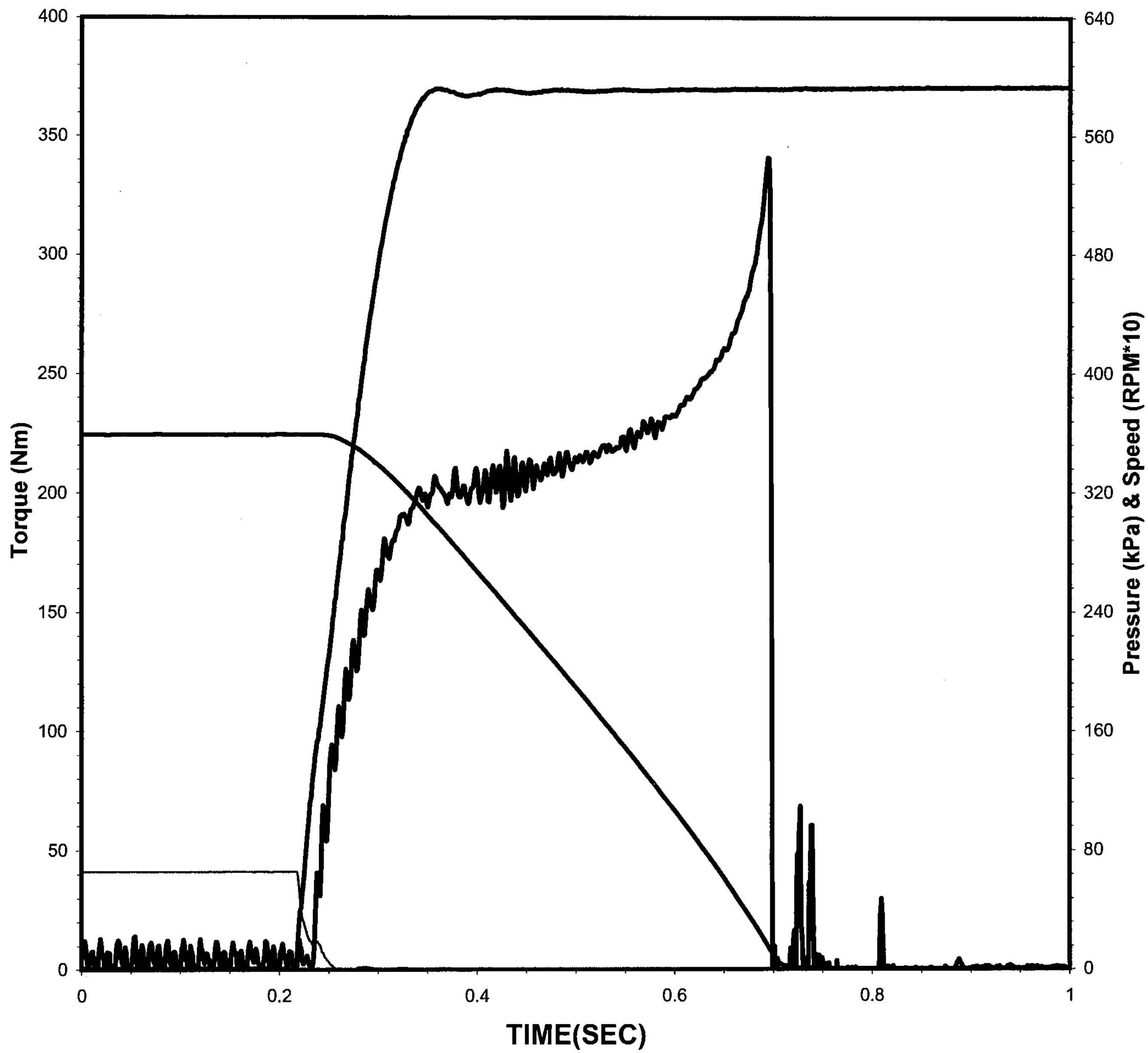
0.2 Sec Dyn:	**204 N*m**
Midpoint Dyn:	**208 N*m**
LwSpd Dynamic:	**341 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.100**
Midpoint Dyn:	**0.101**
LwSpd Dynamic:	**0.166**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/23/2010

Time of Test: 10:35:50

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 501

Temperature: 87.6 °C (93.3 ± 3.0 °C)

Apply Pressure: 589 kPa (586 ± 7 KPa)

Apply Rate: 0.13 Sec (0.15 ± 0.02 Sec)

Energy: 18.6 KJ (18.7 ± 0.40 KJ)

Engage Time: 0.48 Sec

Torque

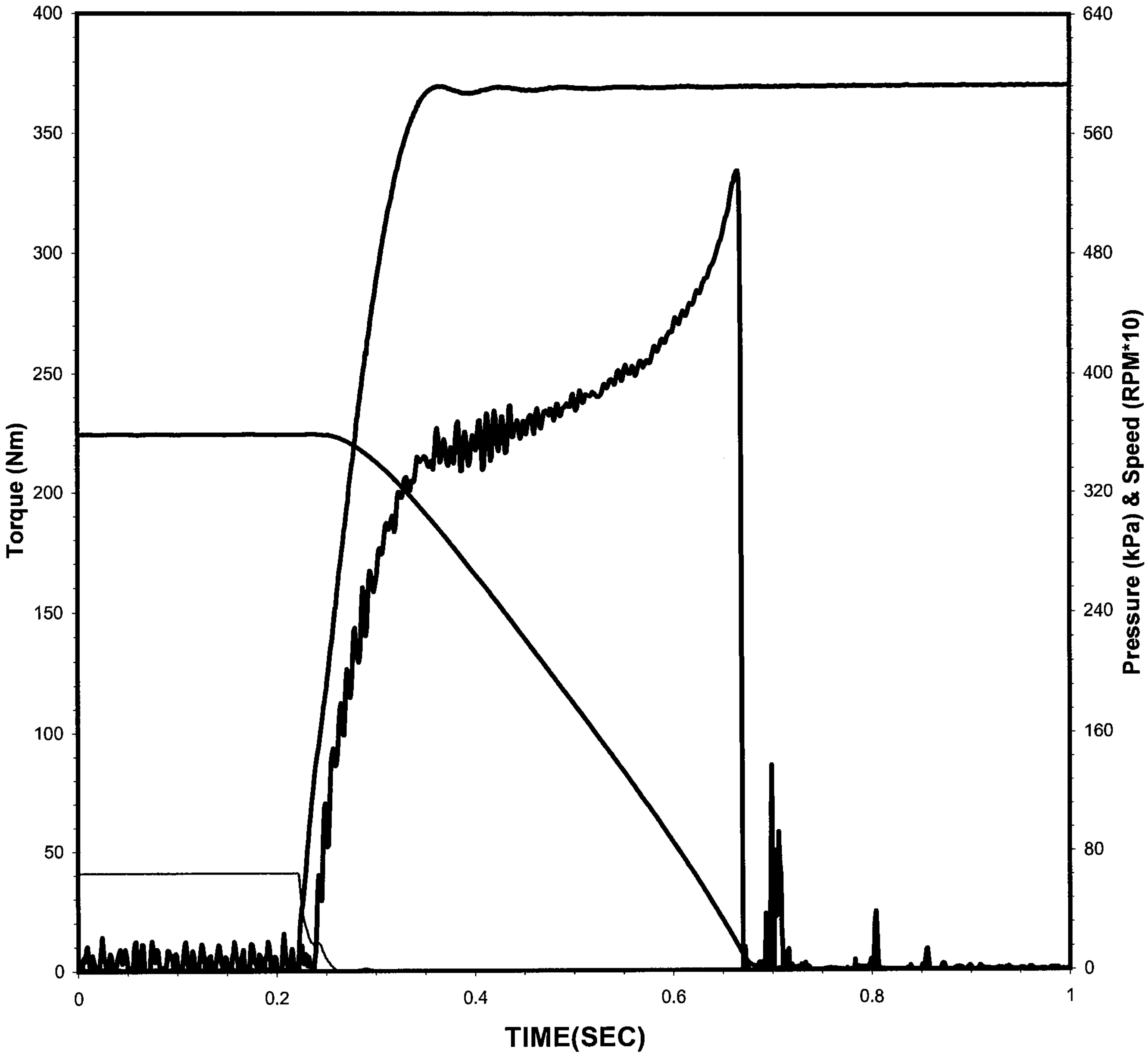
0.2 Sec Dyn:	203 N*m
Midpoint Dyn:	207 N*m
LwSpd Dynamic:	340 N*m

Coefficient of Friction

.2 Sec Dyn:	0.099
Midpoint Dyn:	0.101
LwSpd Dynamic:	0.166

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/23/2010
Time of Test:	12:40:20
Test Number:	C2-7-1552
Fluid Code:	LO253071
Cycle Number:	999
Temperature:	93.3 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	589 kPa
	(586 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.6 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.447 Sec

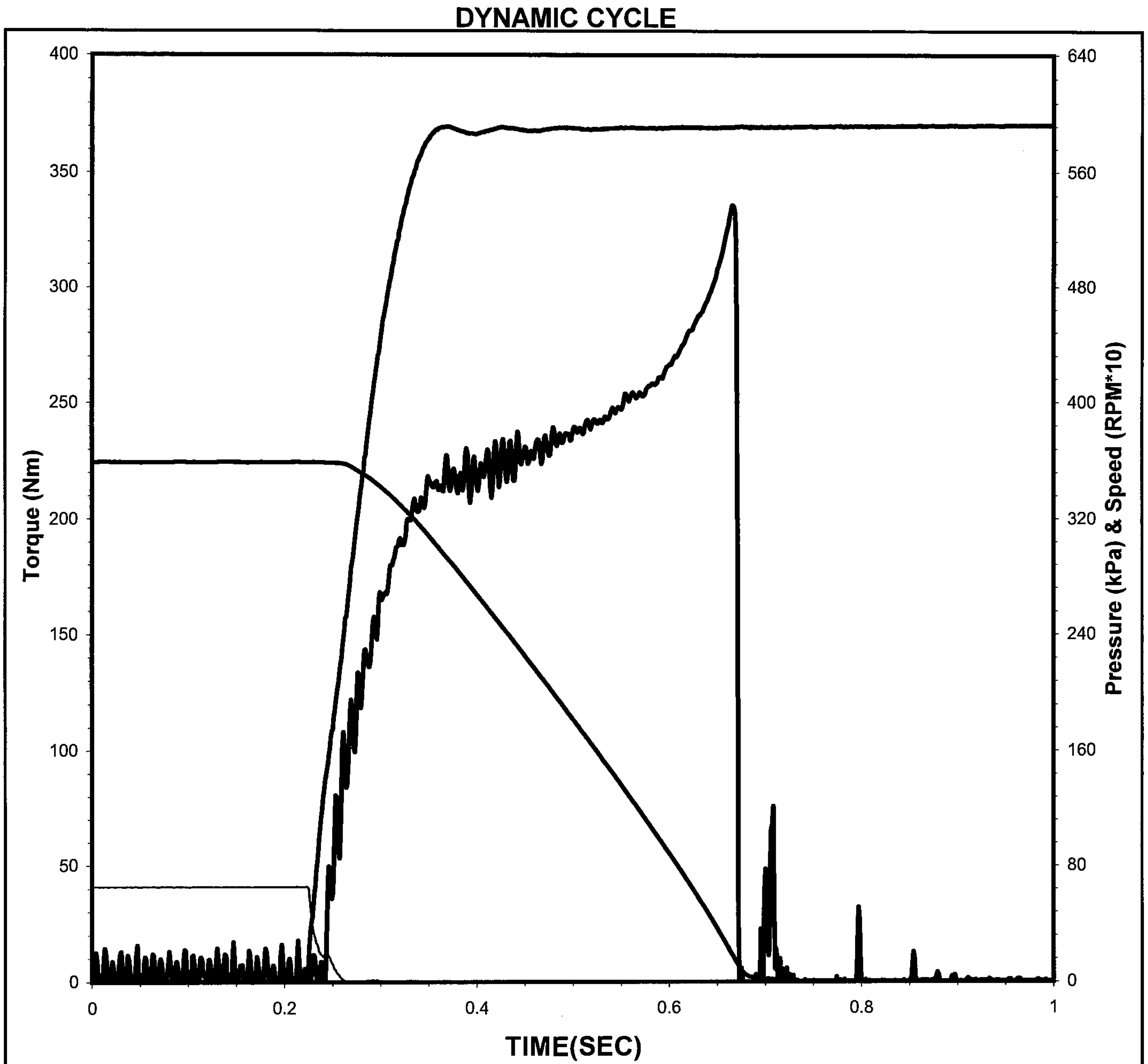
Torque

0.2 Sec Dyn:	223 N*m
Midpoint Dyn:	227 N*m
LwSpd Dynamic:	330 N*m

Coefficient of Friction

.2 Sec Dyn:	0.109
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.161

ALLISON C-4 PAPER DATA



Date of Test: 7/23/2010

Time of Test: 12:40:35

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 1000

Temperature: 93.0 °C
(93.3 ± 3.0 °C)

Apply Pressure: 589 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.448 Sec

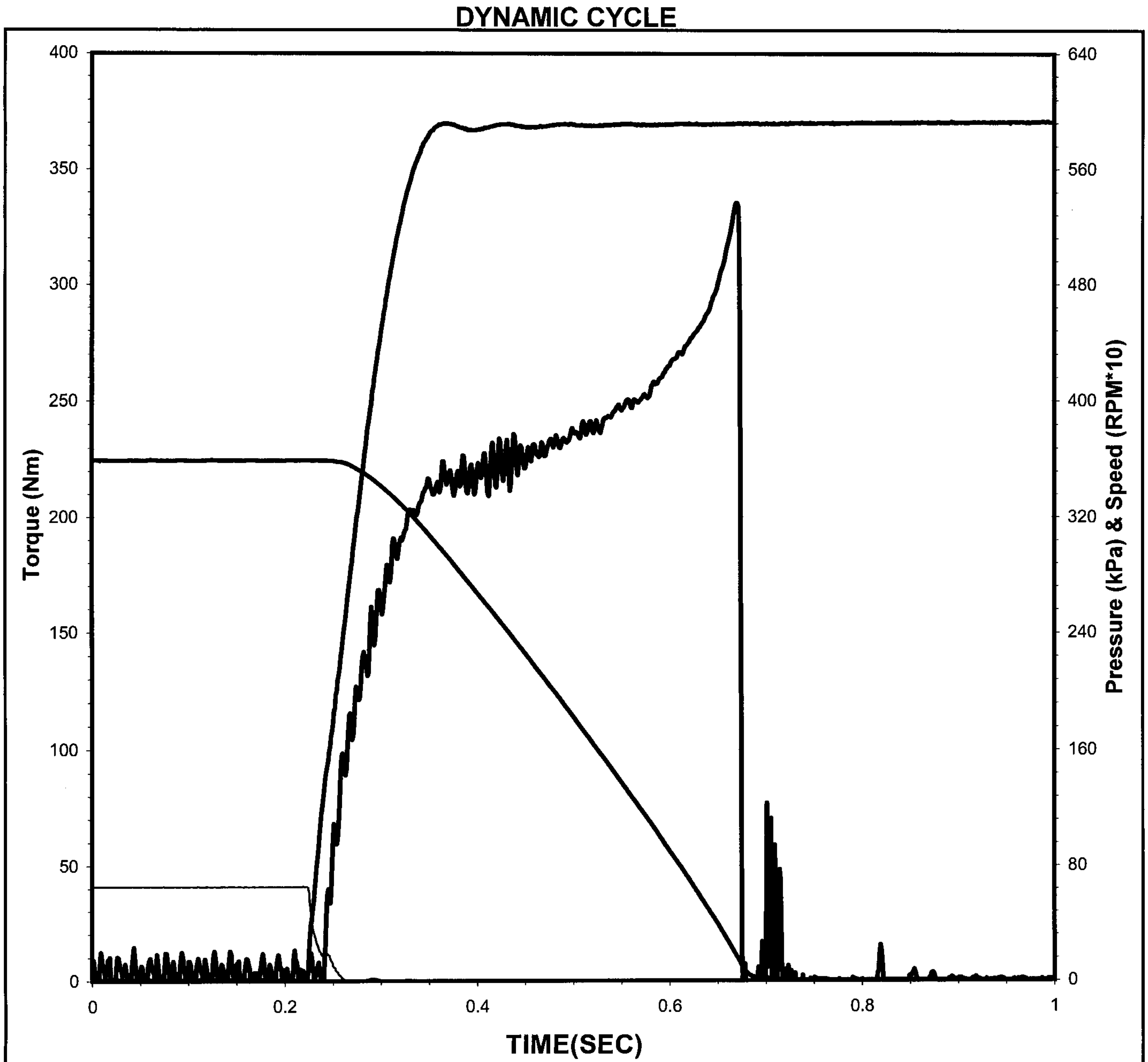
Torque

0.2 Sec Dyn:	225 N*m
Midpoint Dyn:	227 N*m
LwSpd Dynamic:	332 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.162

ALLISON C-4 PAPER DATA



Date of Test:	7/23/2010
Time of Test:	12:41:06
Test Number:	C2-7-1552
Fluid Code:	LO253071
Cycle Number:	1001
Temperature:	86.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.45 Sec

Torque

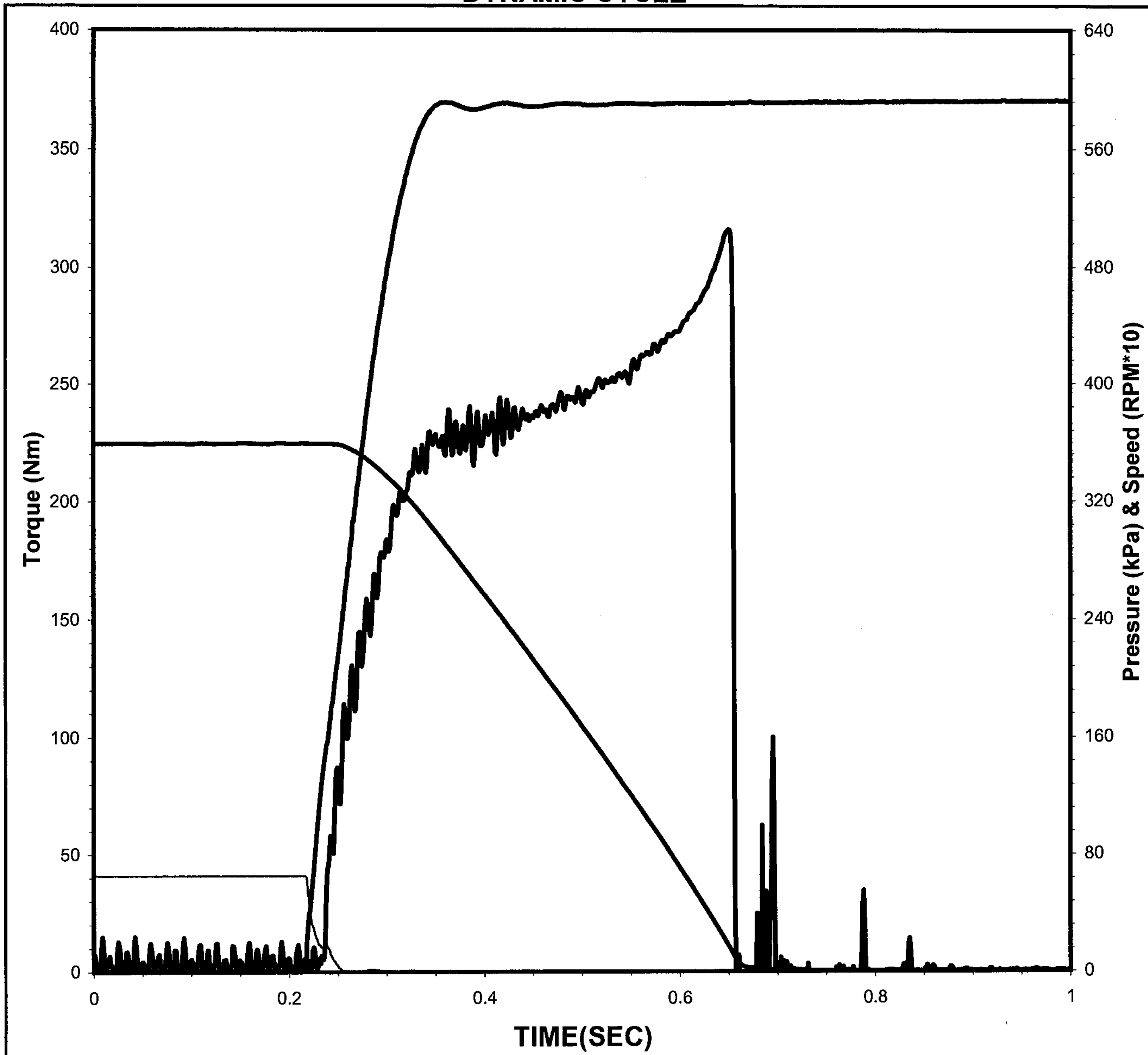
0.2 Sec Dyn:	222 N*m
Midpoint Dyn:	226 N*m
LwSpd Dynamic:	334 N*m

Coefficient of Friction

.2 Sec Dyn:	0.108
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.162

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/23/2010**
Time of Test:	**18:55:36**
Test Number:	**C2-7-1552**
Fluid Code:	**LO253071**
Cycle Number:	**2499**
Temperature:	**93.1 °C**
	(93.3 ± 3.0 °C)
Apply Pressure:	**589 kPa**
	(586 ± 7 KPa)
Apply Rate:	**0.13 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.6 KJ**
	(18.7 ± 0.40 KJ)
Engage Time:	**0.439 Sec**

Torque

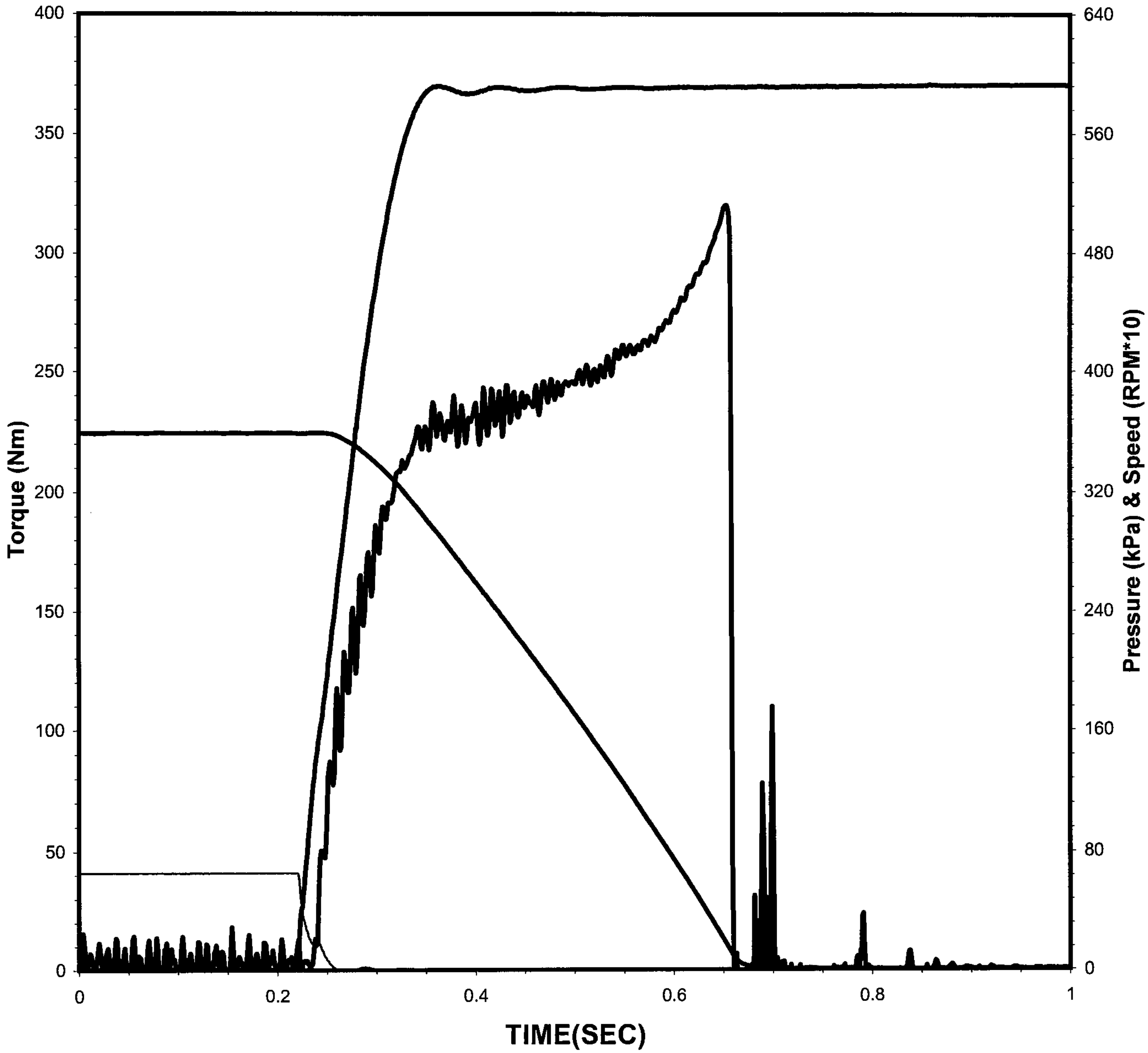
0.2 Sec Dyn:	**232 N*m**
Midpoint Dyn:	**235 N*m**
LwSpd Dynamic:	**312 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.113**
Midpoint Dyn:	**0.114**
LwSpd Dynamic:	**0.152**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/23/2010
Time of Test:	18:55:51
Test Number:	C2-7-1552
Fluid Code:	LO253071
Cycle Number:	2500
Temperature:	92.8 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.438 Sec

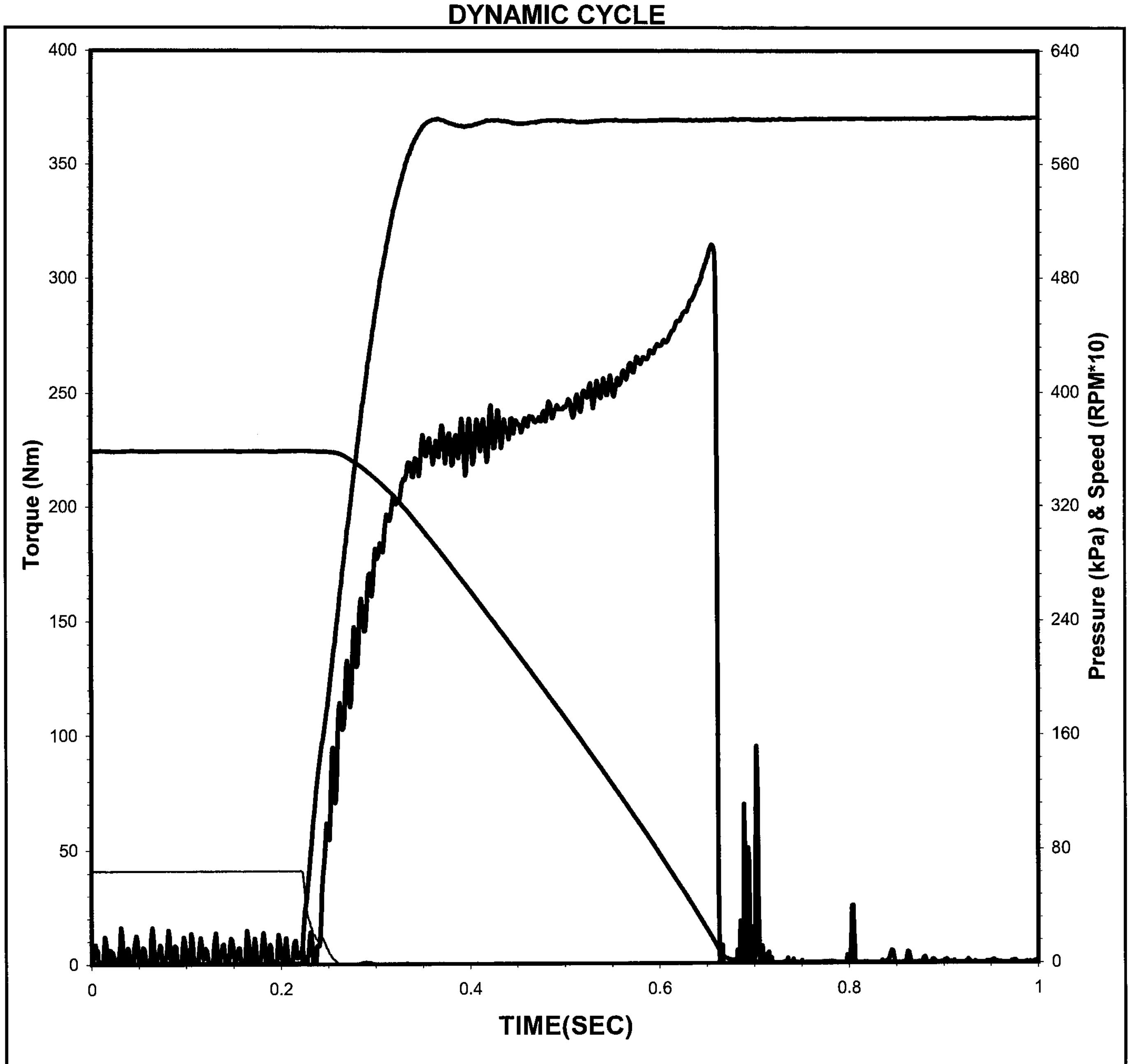
Torque

0.2 Sec Dyn:	234 N*m
Midpoint Dyn:	236 N*m
LwSpd Dynamic:	308 N*m

Coefficient of Friction

.2 Sec Dyn:	0.114
Midpoint Dyn:	0.115
LwSpd Dynamic:	0.150

ALLISON C-4 PAPER DATA



Date of Test:	7/23/2010
Time of Test:	18:56:22
Test Number:	C2-7-1552
Fluid Code:	LO253071
Cycle Number:	2501
Temperature:	87.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.44 Sec

Torque

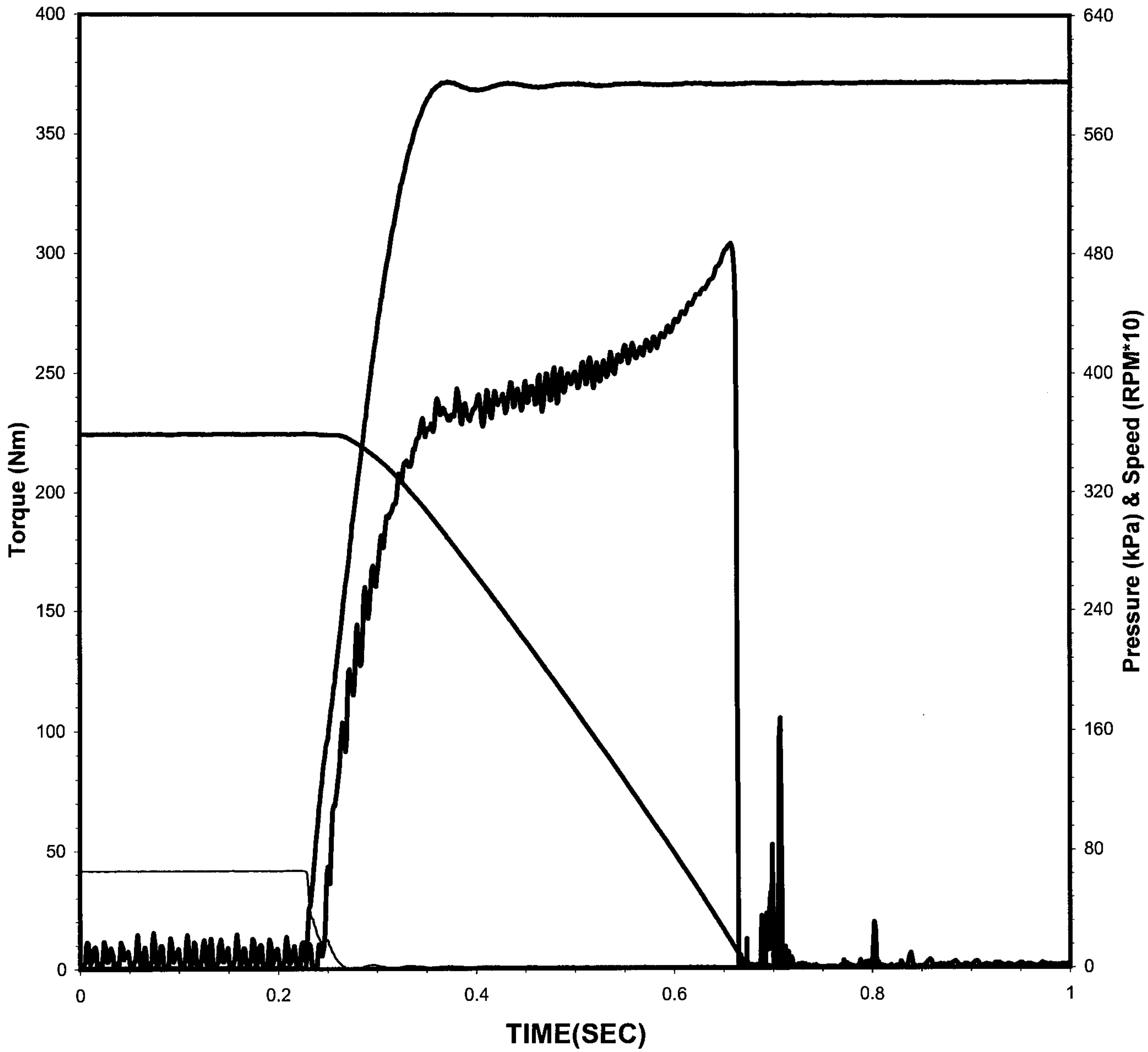
0.2 Sec Dyn:	232 N*m
Midpoint Dyn:	234 N*m
LwSpd Dynamic:	310 N*m

Coefficient of Friction

.2 Sec Dyn:	0.113
Midpoint Dyn:	0.114
LwSpd Dynamic:	0.151

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/24/2010
Time of Test:	5:20:52
Test Number:	C2-7-1552
Fluid Code:	LO253071
Cycle Number:	4999
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	592 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.436 Sec

Torque

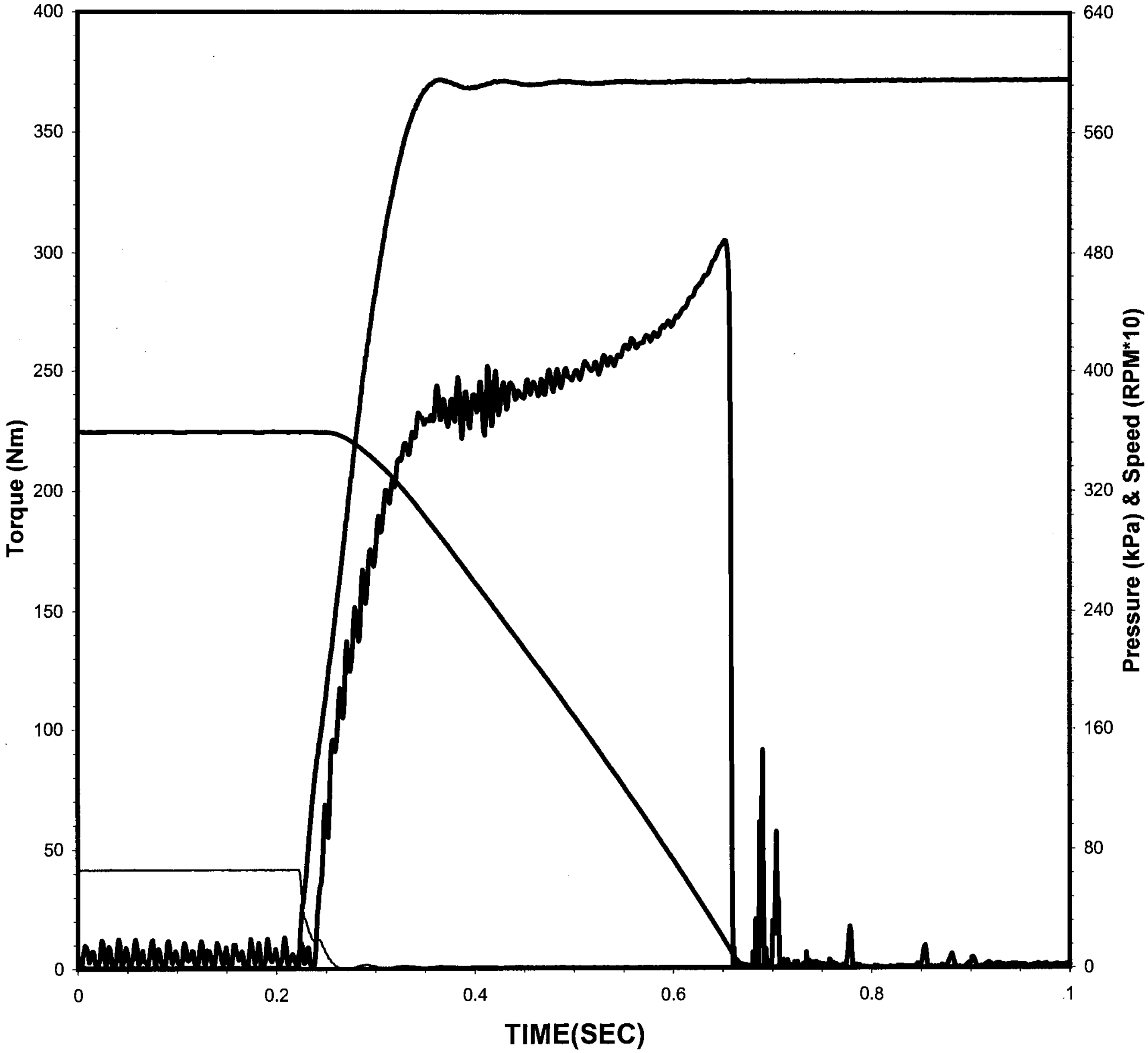
0.2 Sec Dyn:	238 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	289 N*m

Coefficient of Friction

.2 Sec Dyn:	0.116
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.141

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/24/2010
Time of Test:	5:21:07
Test Number:	C2-7-1552
Fluid Code:	LO253071
Cycle Number:	5000
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	592 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.436 Sec

Torque

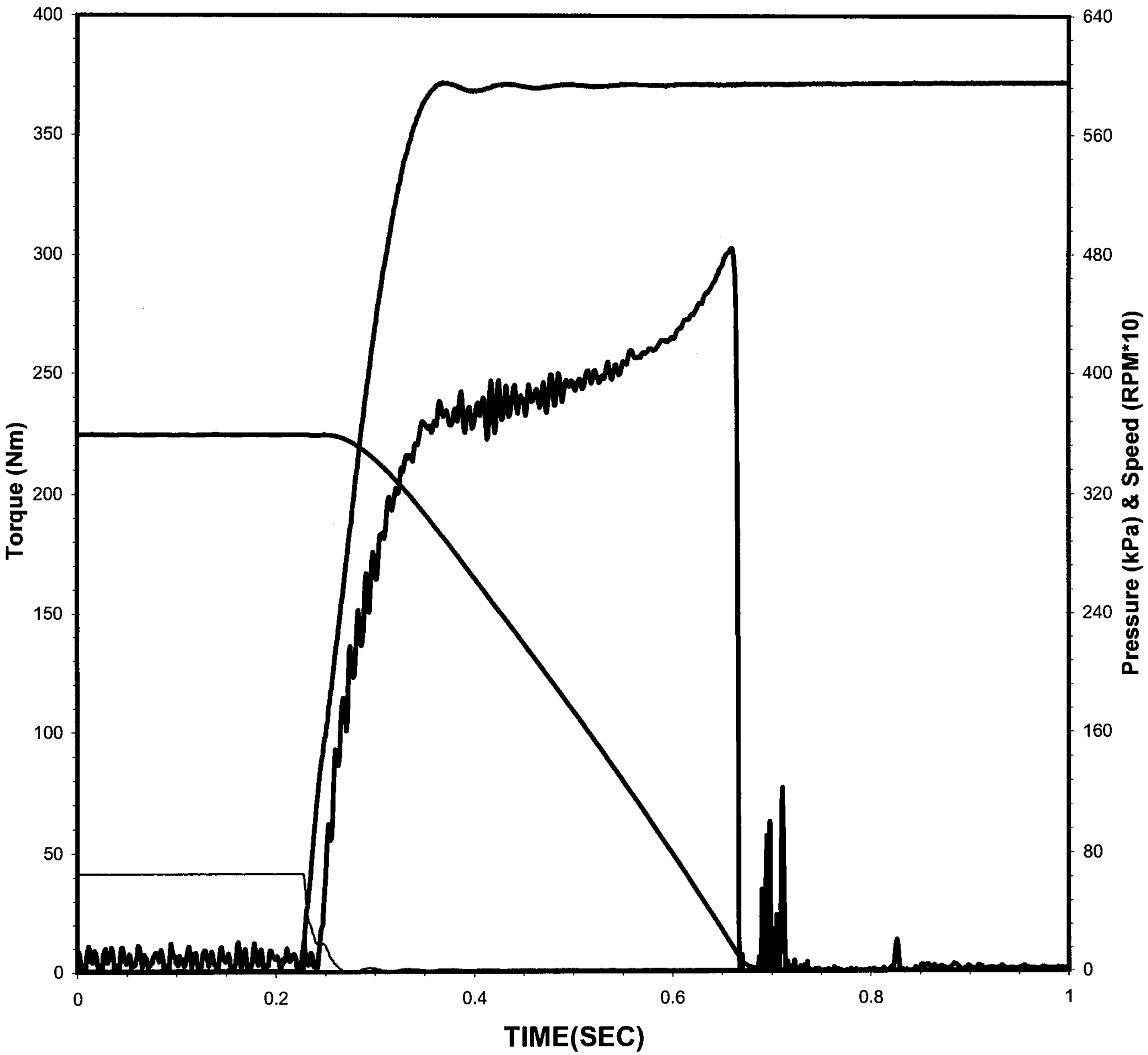
0.2 Sec Dyn:	237 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	298 N*m

Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.145

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/24/2010

Time of Test: 5:21:39

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 5001

Temperature: 86.9 °C
(93.3 ± 3.0 °C)

Apply Pressure: 592 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.439 Sec

Torque

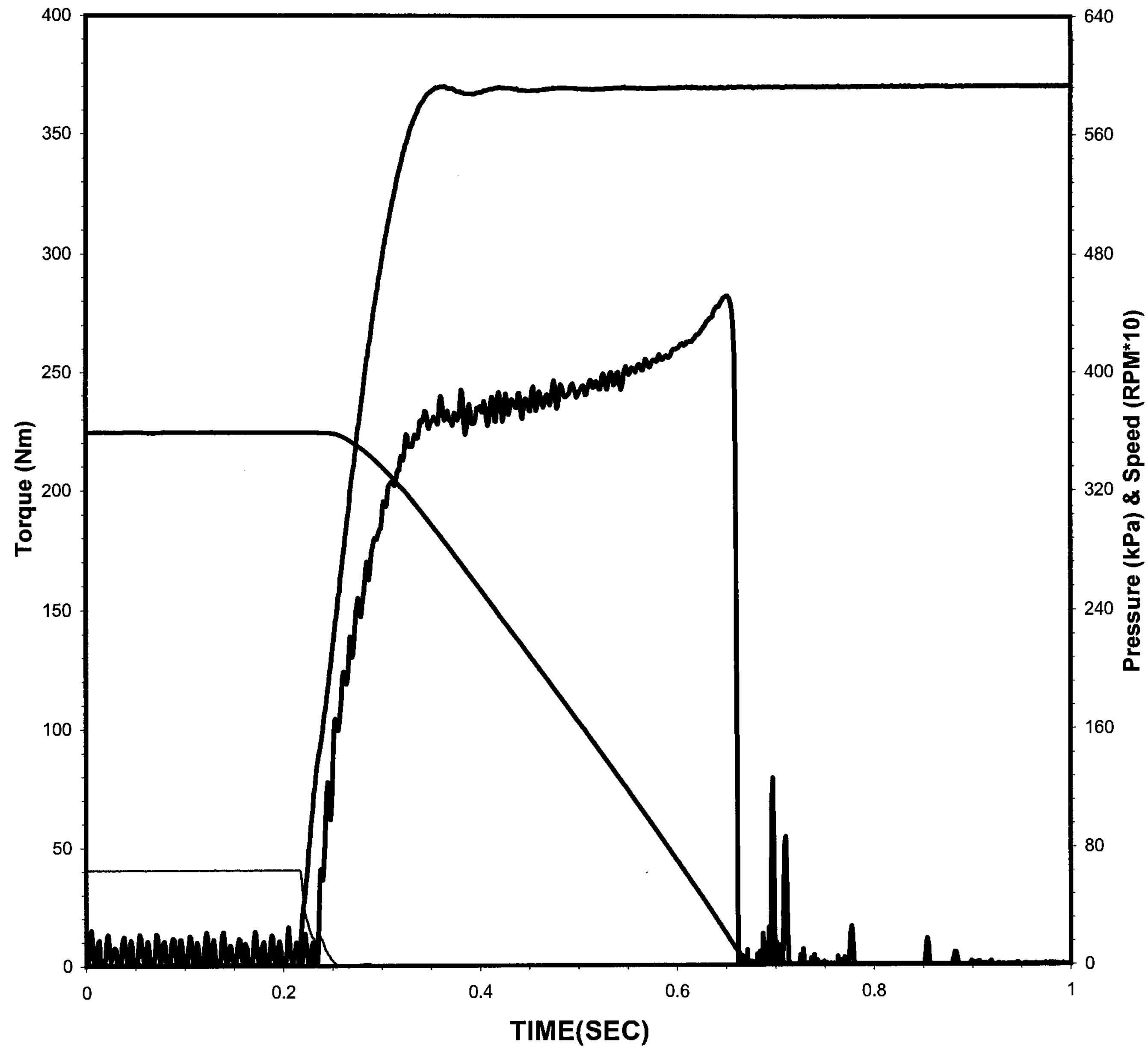
0.2 Sec Dyn:	235 N*m
Midpoint Dyn:	238 N*m
LwSpd Dynamic:	290 N*m

Coefficient of Friction

.2 Sec Dyn:	0.114
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.141

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/24/2010**
Time of Test:	**15:46:09**
Test Number:	**C2-7-1552**
Fluid Code:	**LO253071**
Cycle Number:	**7499**
Temperature:	**94.5 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**590 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.6 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.444 Sec**

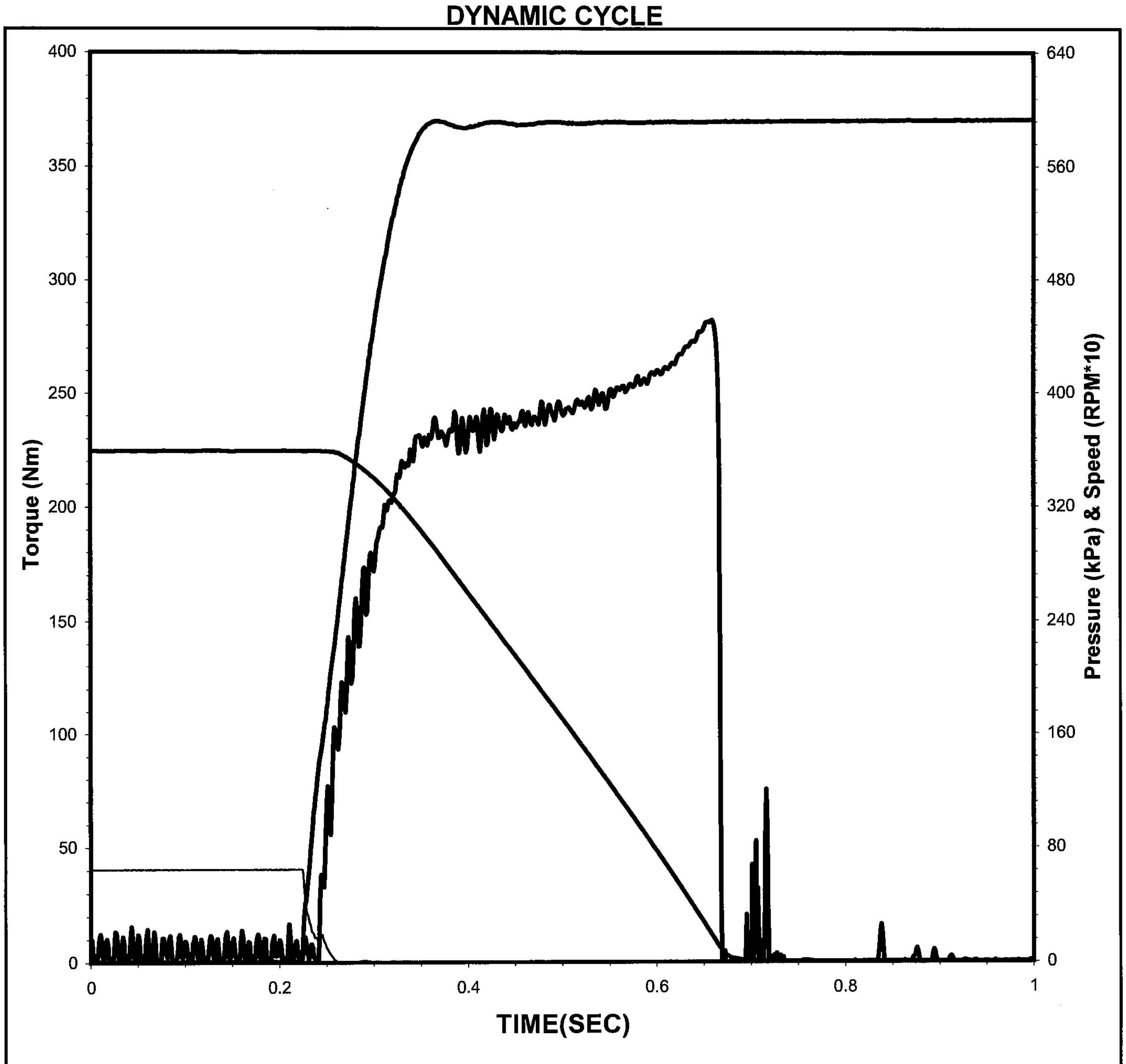
Torque

0.2 Sec Dyn:	**235 N*m**
Midpoint Dyn:	**236 N*m**
LwSpd Dynamic:	**269 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.115**
Midpoint Dyn:	**0.115**
LwSpd Dynamic:	**0.131**

ALLISON C-4 PAPER DATA



Date of Test: 7/24/2010

Time of Test: 15:46:24

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 7500

Temperature: 94.3 °C
(93.3 ± 3.0 °C)

Apply Pressure: 590 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.7 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.444 Sec

Torque

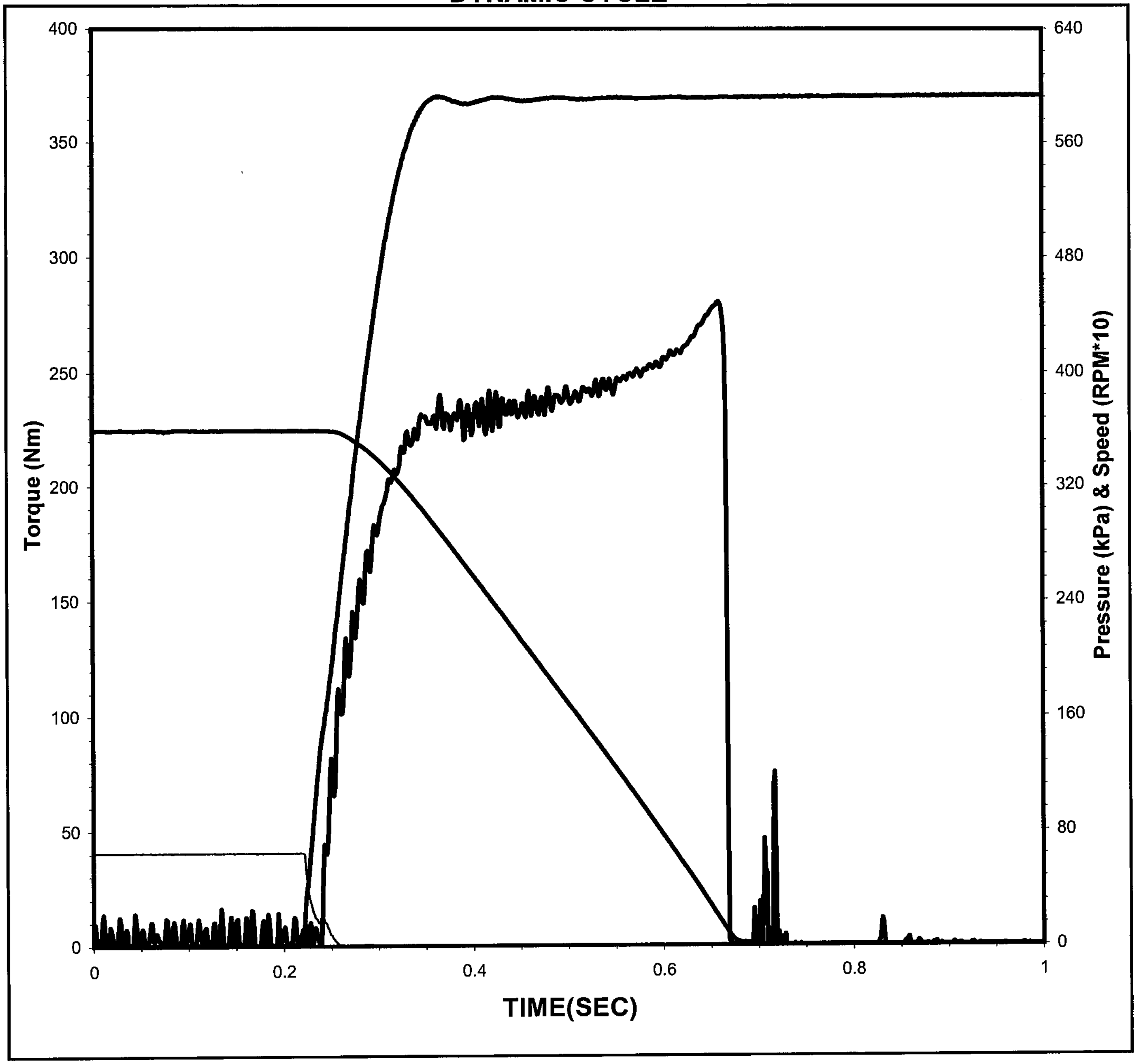
0.2 Sec Dyn:	235 N*m
Midpoint Dyn:	237 N*m
LwSpd Dynamic:	266 N*m

Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.115
LwSpd Dynamic:	0.130

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: **7/24/2010**

Time of Test: **15:46:55**

Test Number: **C2-7-1552**

Fluid Code: **LO253071**

Cycle Number: **7501**

Temperature: **87.2 °C**
(93.3 ± 3.0 °C)

Apply Pressure: **590 kPa**
(586 ± 7 KPa)

Apply Rate: **0.13 Sec**
(0.15 ± 0.02 Sec)

Energy: **18.6 KJ**
(18.7 ± 0.40 KJ)

Engage Time: **0.448 Sec**

Torque

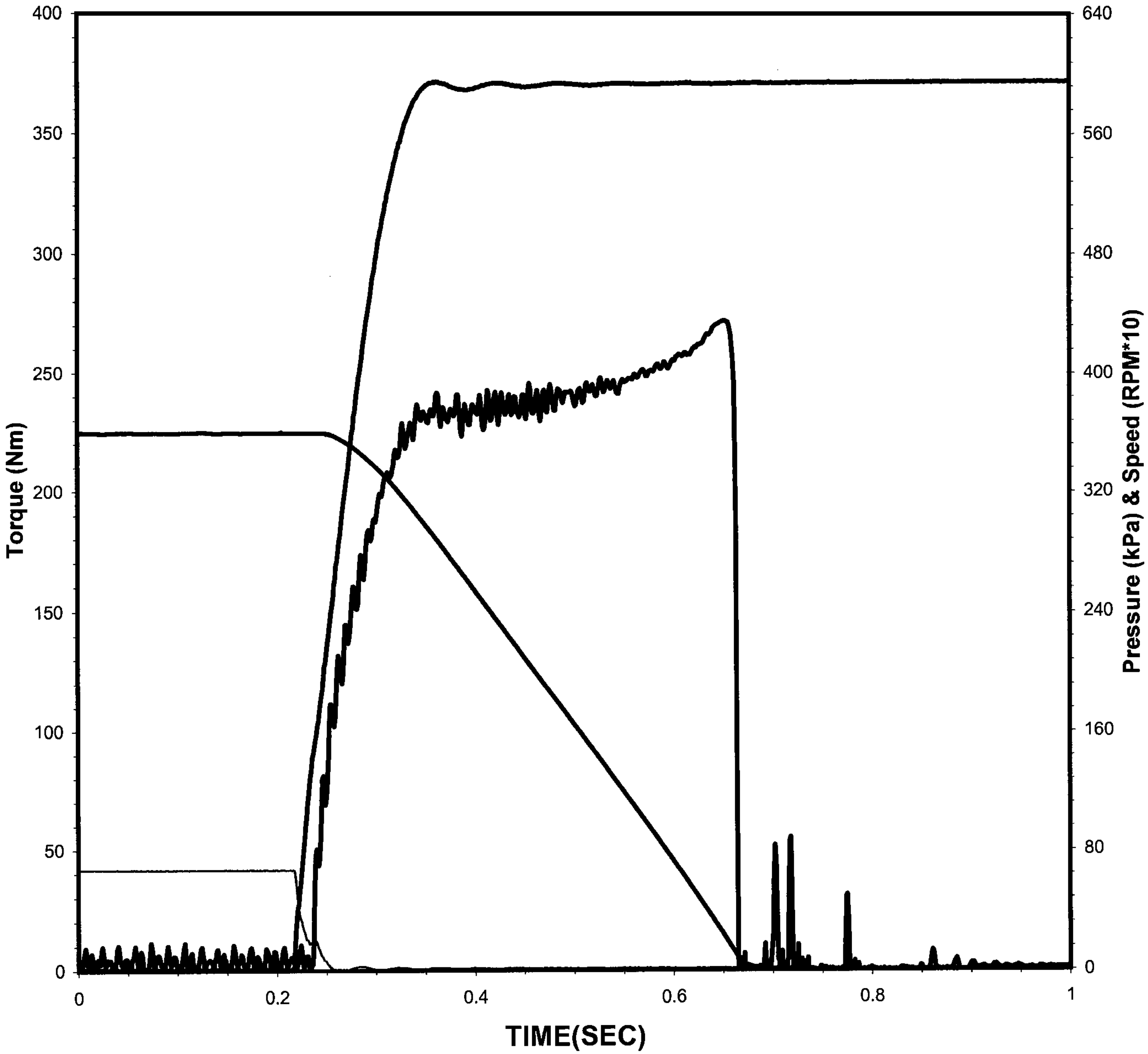
0.2 Sec Dyn: **233 N*m**
Midpoint Dyn: **234 N*m**
LwSpd Dynamic: **268 N*m**

Coefficient of Friction

.2 Sec Dyn: **0.114**
Midpoint Dyn: **0.114**
LwSpd Dynamic: **0.130**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/25/2010
Time of Test:	2:11:10
Test Number:	C2-7-1552
Fluid Code:	LO253071
Cycle Number:	9998
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	592 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.446 Sec

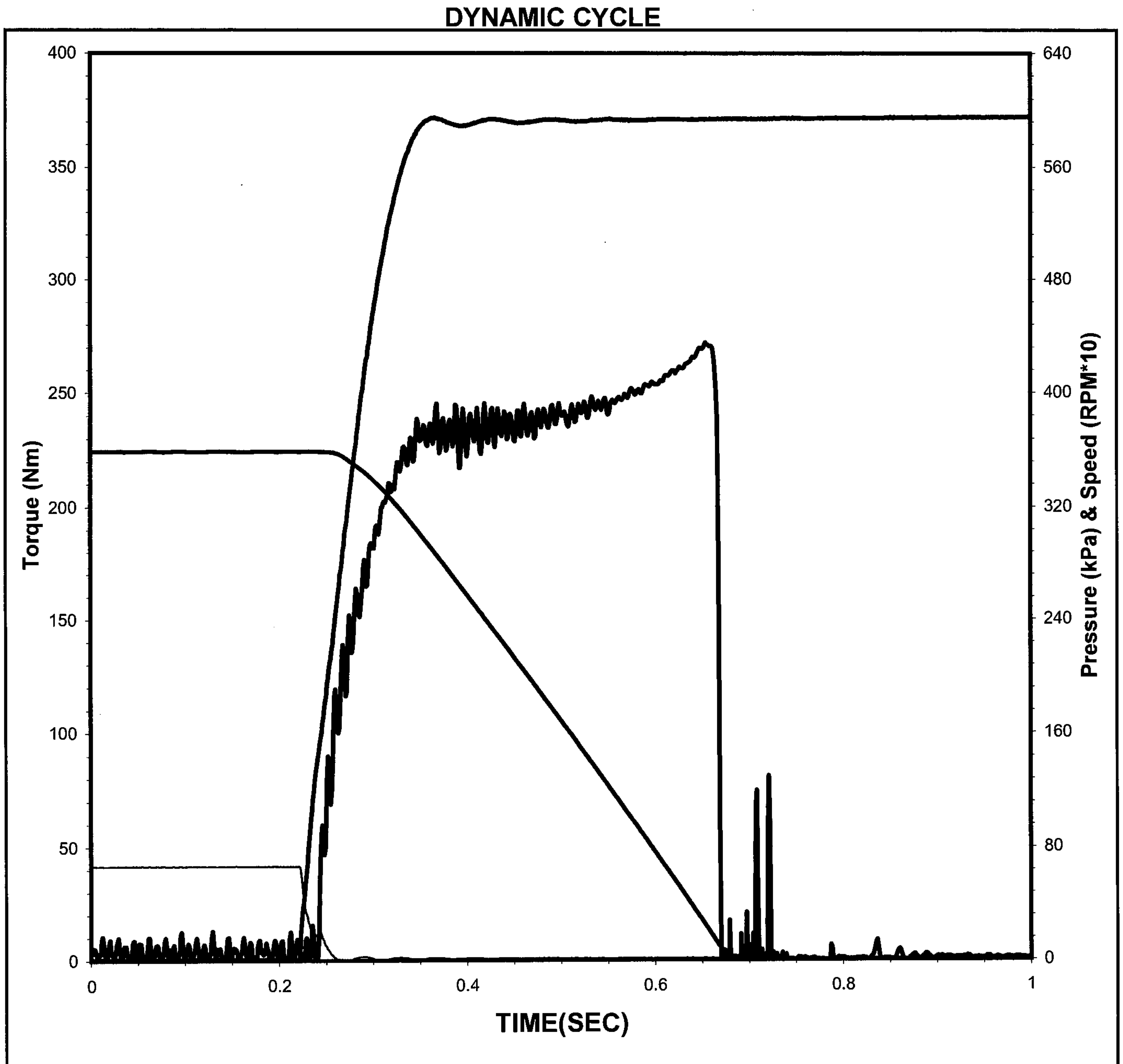
Torque

0.2 Sec Dyn:	235 N*m
Midpoint Dyn:	235 N*m
LwSpd Dynamic:	256 N*m

Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.115
LwSpd Dynamic:	0.124

ALLISON C-4 PAPER DATA



Date of Test: 7/25/2010

Time of Test: 2:11:25

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 9999

Temperature: 92.9 °C
(93.3 ± 3.0 °C)

Apply Pressure: 592 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.447 Sec

Torque

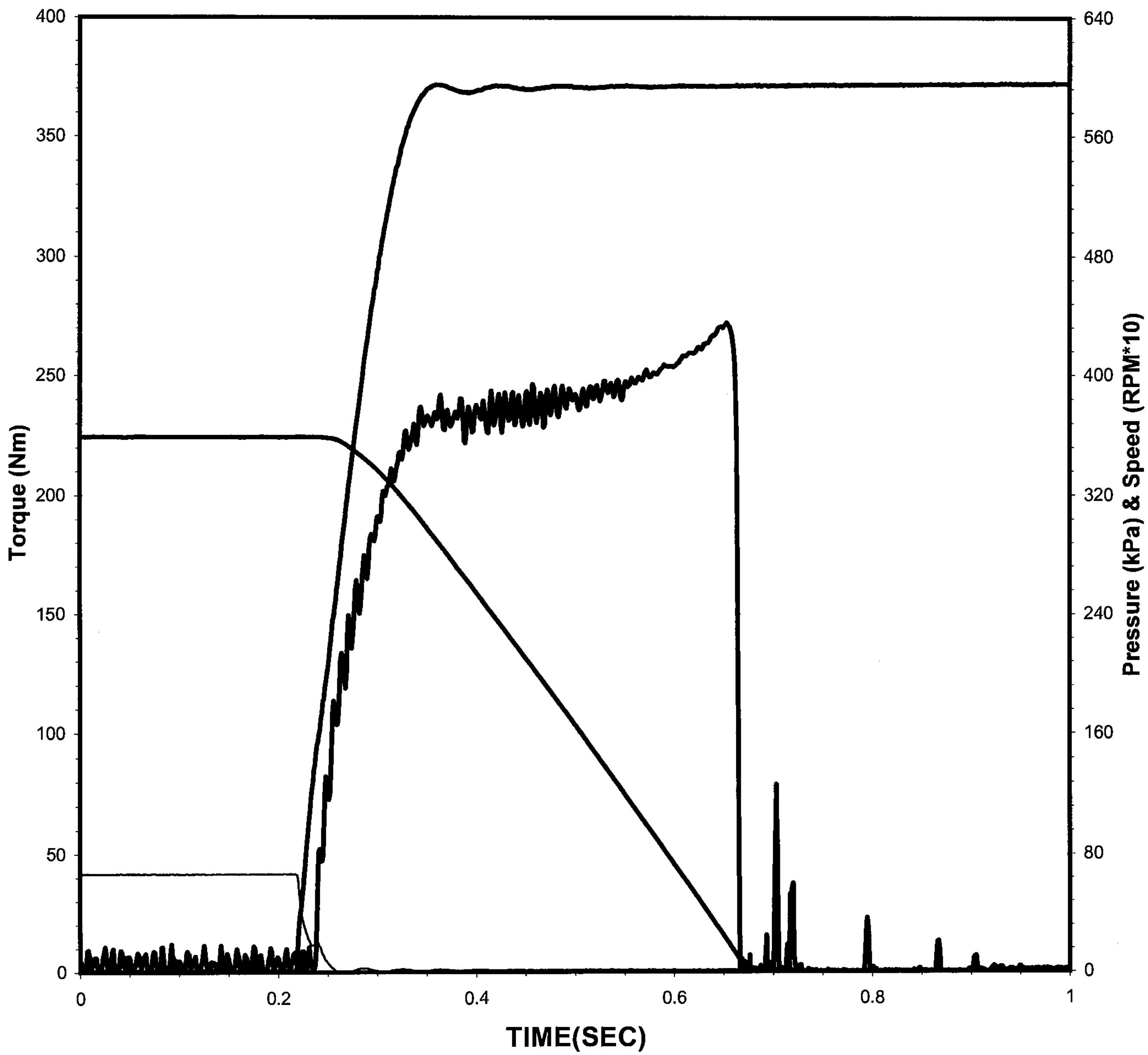
0.2 Sec Dyn: 234 N*m
Midpoint Dyn: 235 N*m
LwSpd Dynamic: 258 N*m

Coefficient of Friction

.2 Sec Dyn: 0.114
Midpoint Dyn: 0.114
LwSpd Dynamic: 0.125

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/25/2010**
Time of Test:	**2:11:40**
Test Number:	**C2-7-1552**
Fluid Code:	**LO253071**
Cycle Number:	**10000**
Temperature:	**92.9 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**592 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.6 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.446 Sec**

Torque

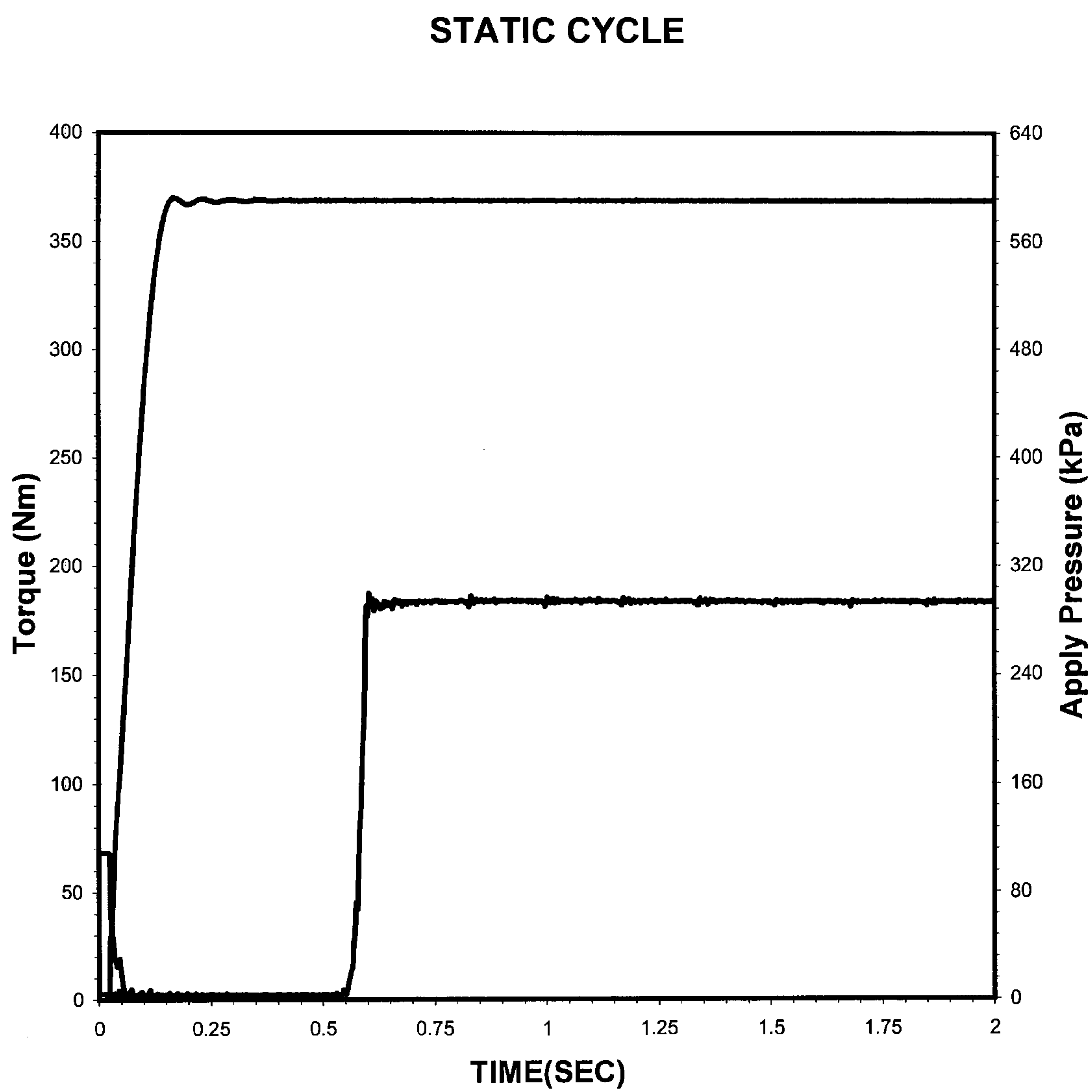
0.2 Sec Dyn:	**235 N*m**
Midpoint Dyn:	**235 N*m**
LwSpd Dynamic:	**254 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.114**
Midpoint Dyn:	**0.114**
LwSpd Dynamic:	**0.124**

STATIC TRACES

ALLISON C-4 PAPER DATA



Date of Test: 7/23/2010

Time of Test: 8:32:32

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 10

STATIC CYCLE

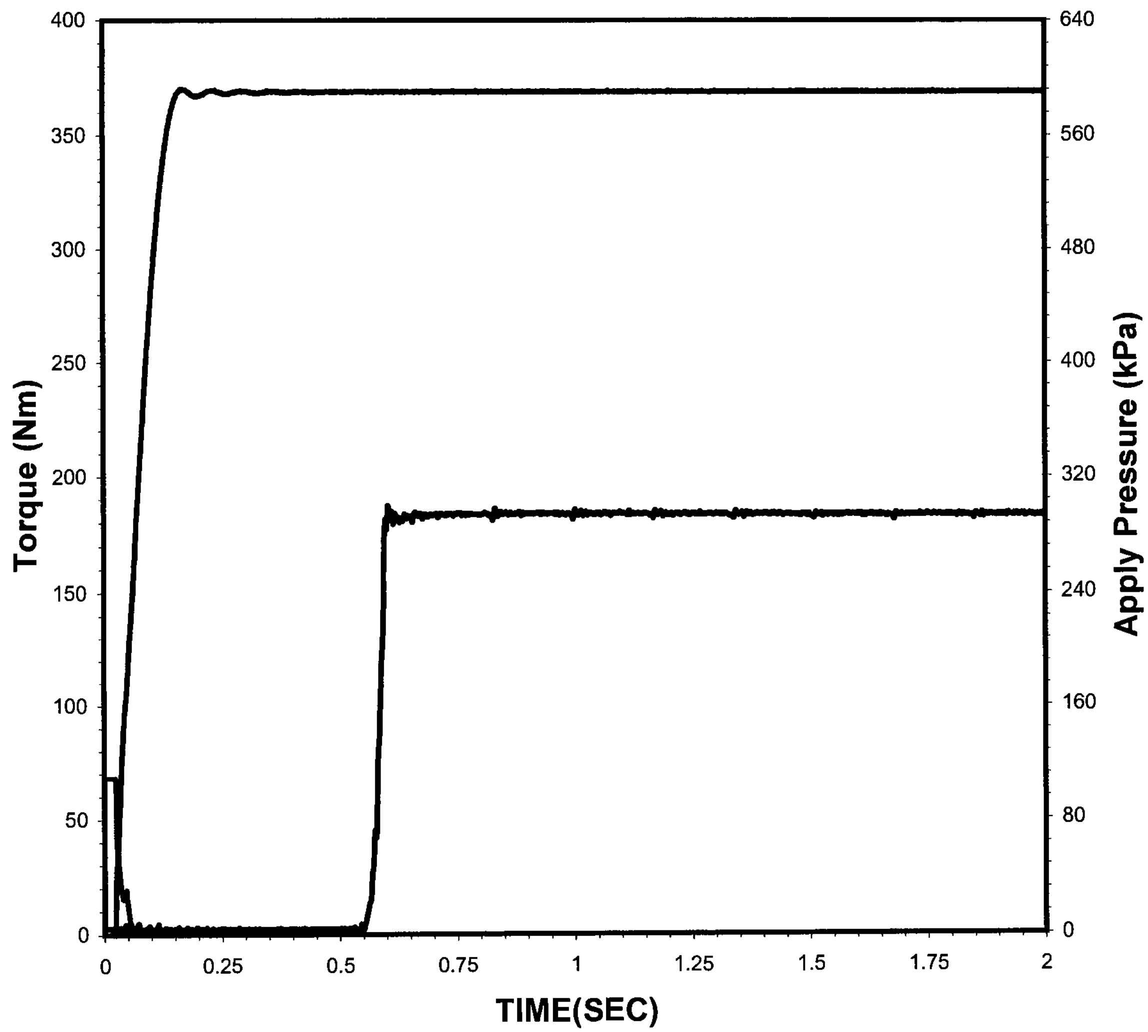
Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 301 Nm
.25 Second: 288 Nm

Coefficient of Friction
Static Peak: 0.147
.25 Second: 0.140

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 8:55:18

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 100

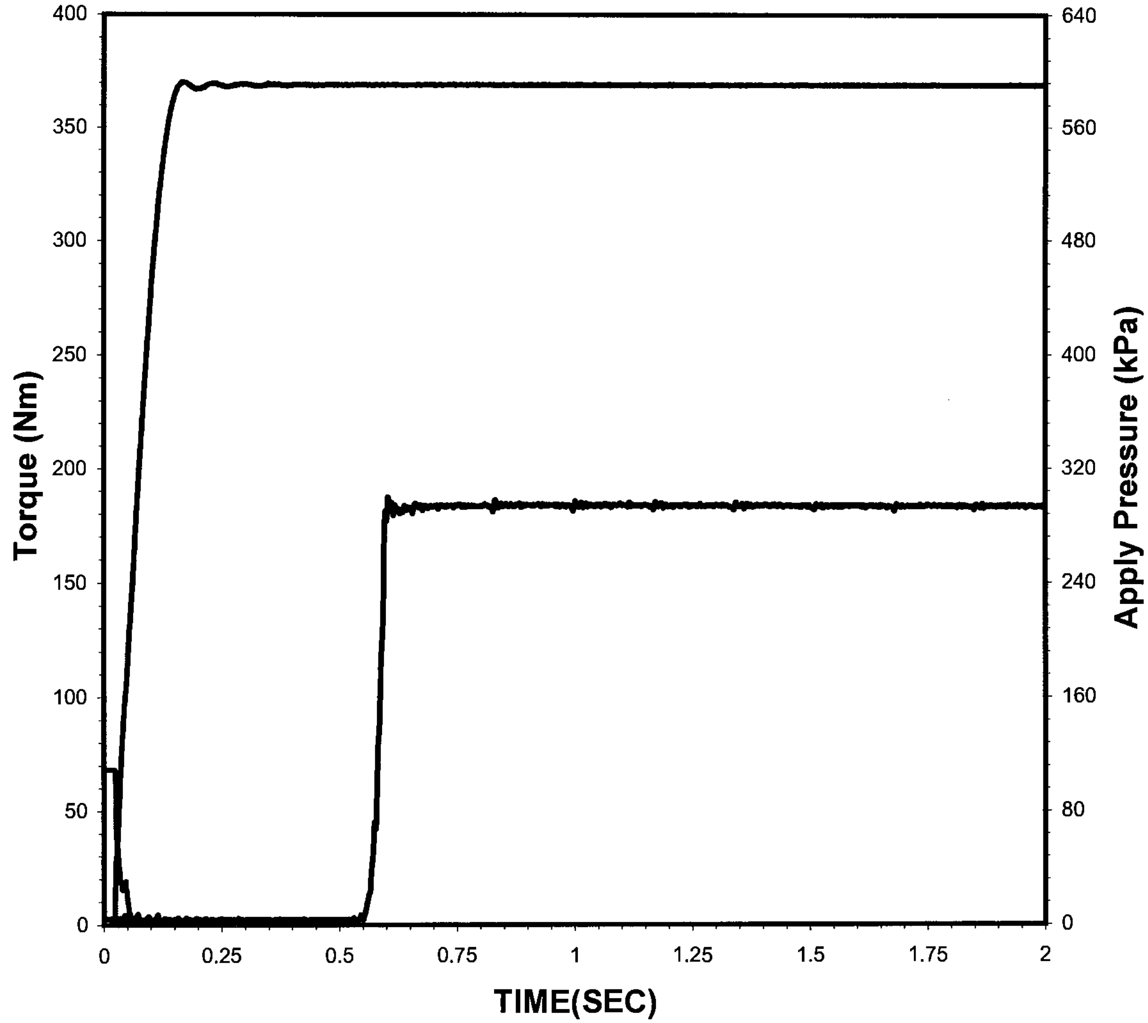
STATIC CYCLE

Apply Pressure:
At .25 Second: 591 kPa

Torque
Static Peak: 355 Nm
.25 Second: 335 Nm

Coefficient of Friction
Static Peak: 0.173
.25 Second: 0.163

ALLISON C-4 PAPER DATA



Date of Test: 7/23/2010

Time of Test: 10:35:35

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 500

STATIC CYCLE

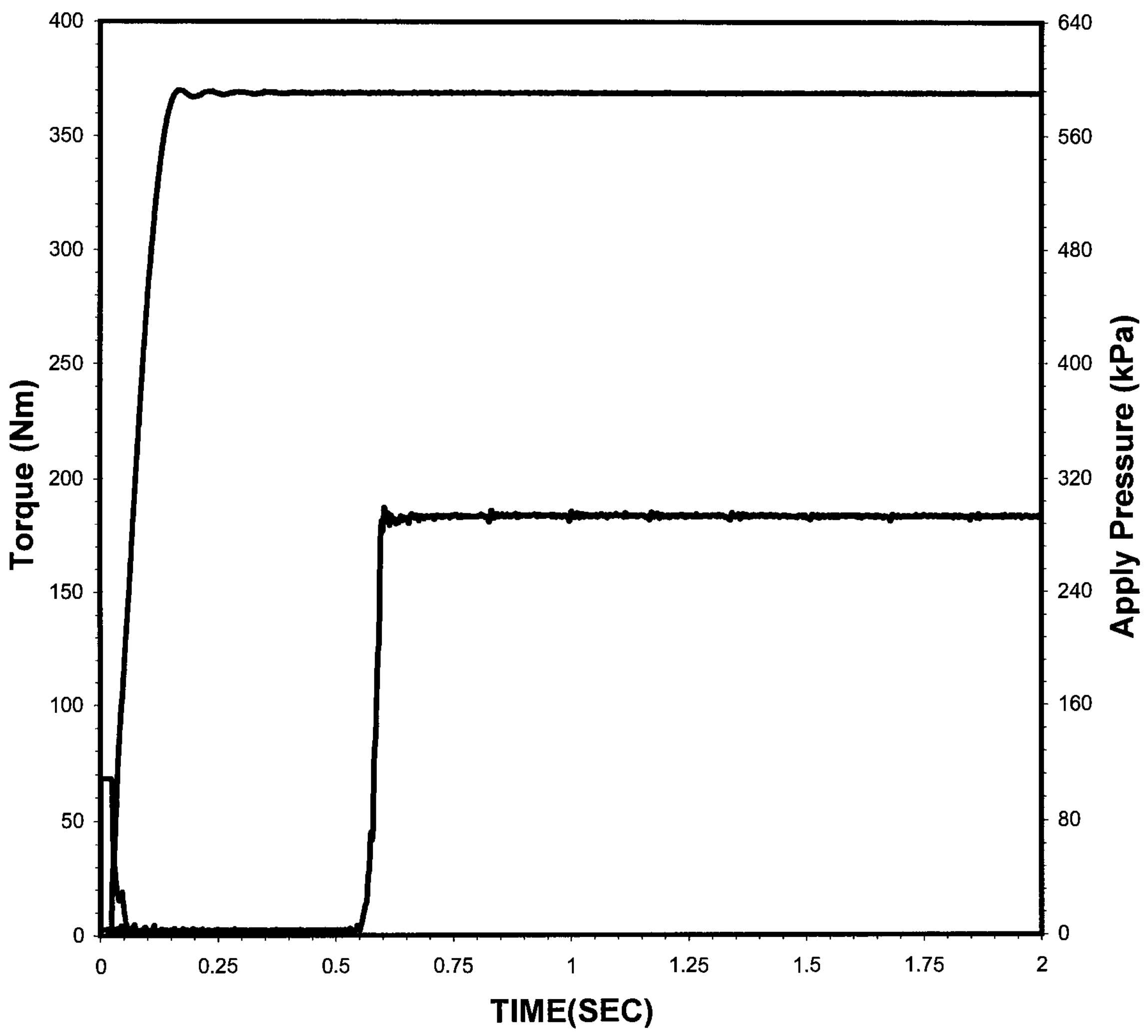
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 356 Nm
.25 Second: 342 Nm

Coefficient of Friction
Static Peak: 0.174
.25 Second: 0.167

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 12:40:51

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 1000

STATIC CYCLE

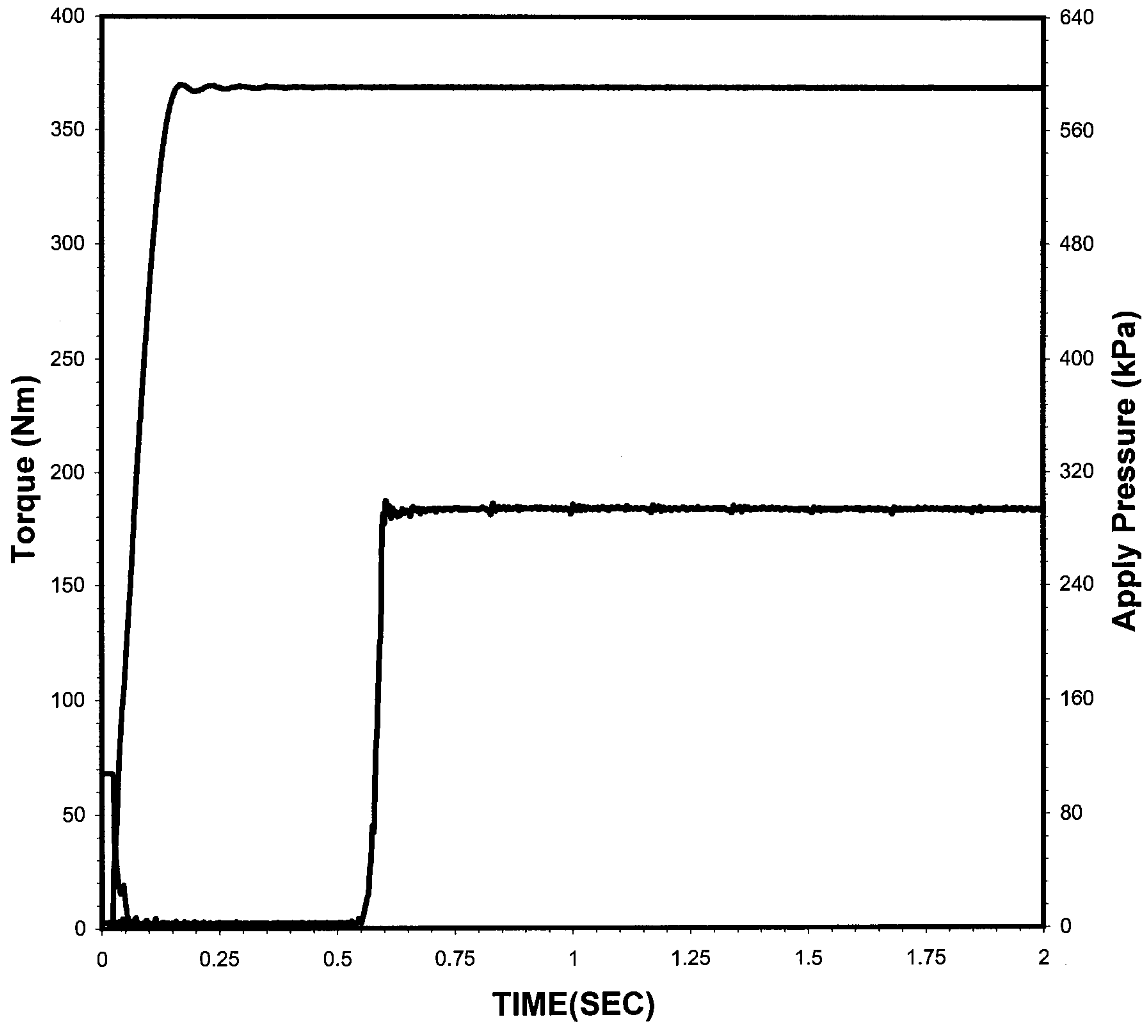
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 359 Nm
.25 Second: 338 Nm

Coefficient of Friction
Static Peak: 0.175
.25 Second: 0.165

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 18:56:07

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 2500

STATIC CYCLE

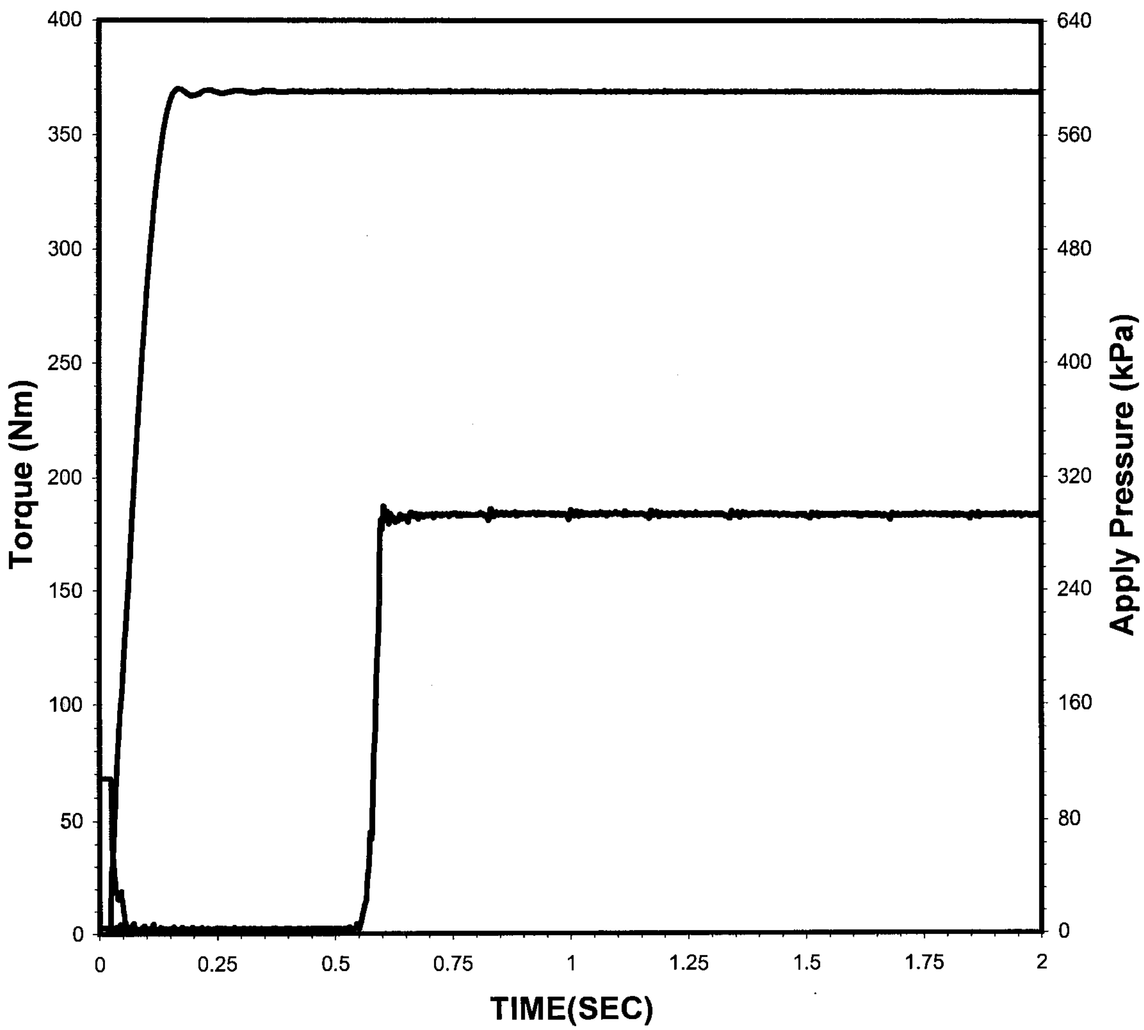
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 337 Nm
.25 Second: 315 Nm

Coefficient of Friction
Static Peak: 0.164
.25 Second: 0.153

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/24/2010

Time of Test: 5:21:23

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 5000

STATIC CYCLE

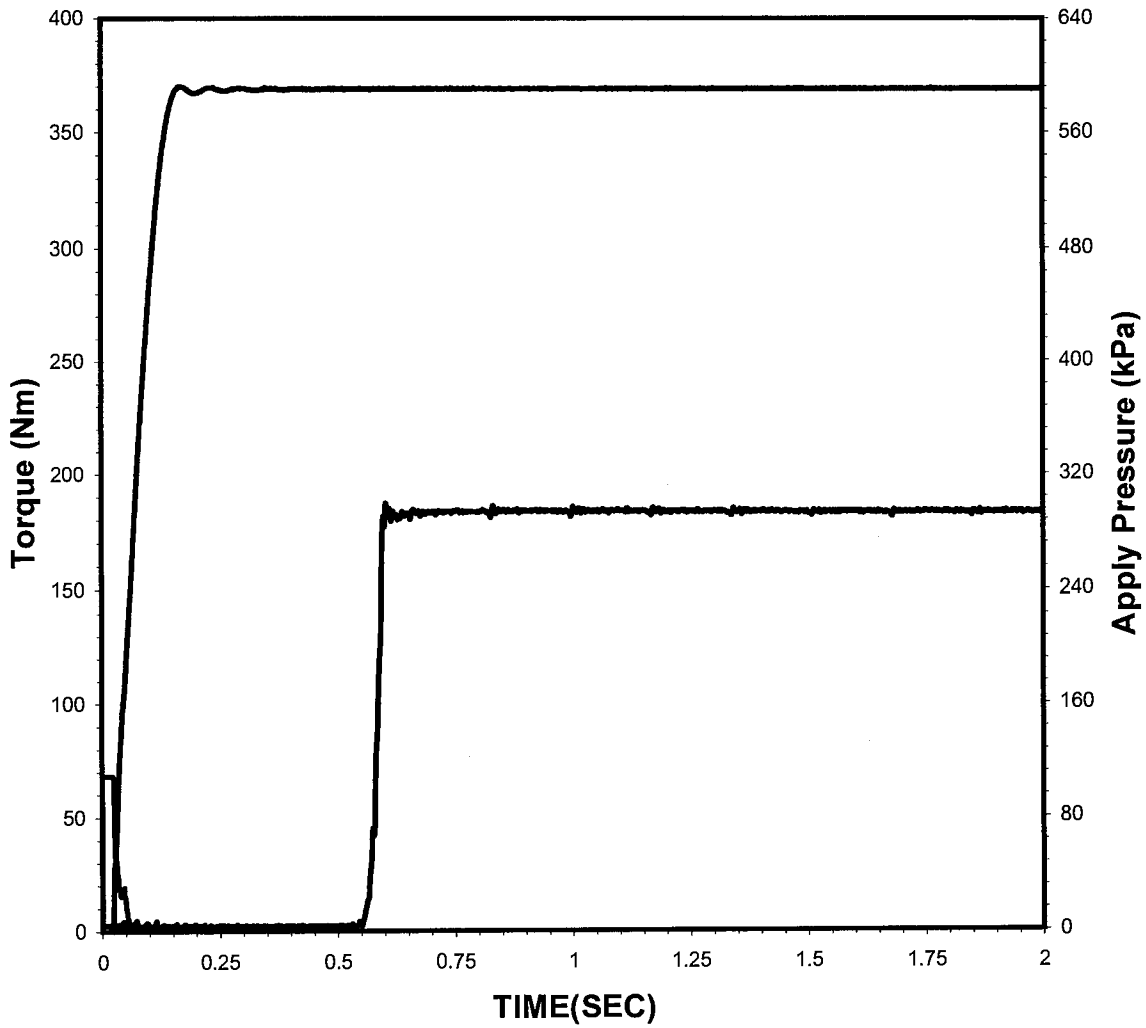
Apply Pressure:
At .25 Second: 592 kPa

Torque
Static Peak: 332 Nm
.25 Second: 302 Nm

Coefficient of Friction
Static Peak: 0.162
.25 Second: 0.147

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/24/2010

Time of Test: 15:46:40

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 7500

STATIC CYCLE

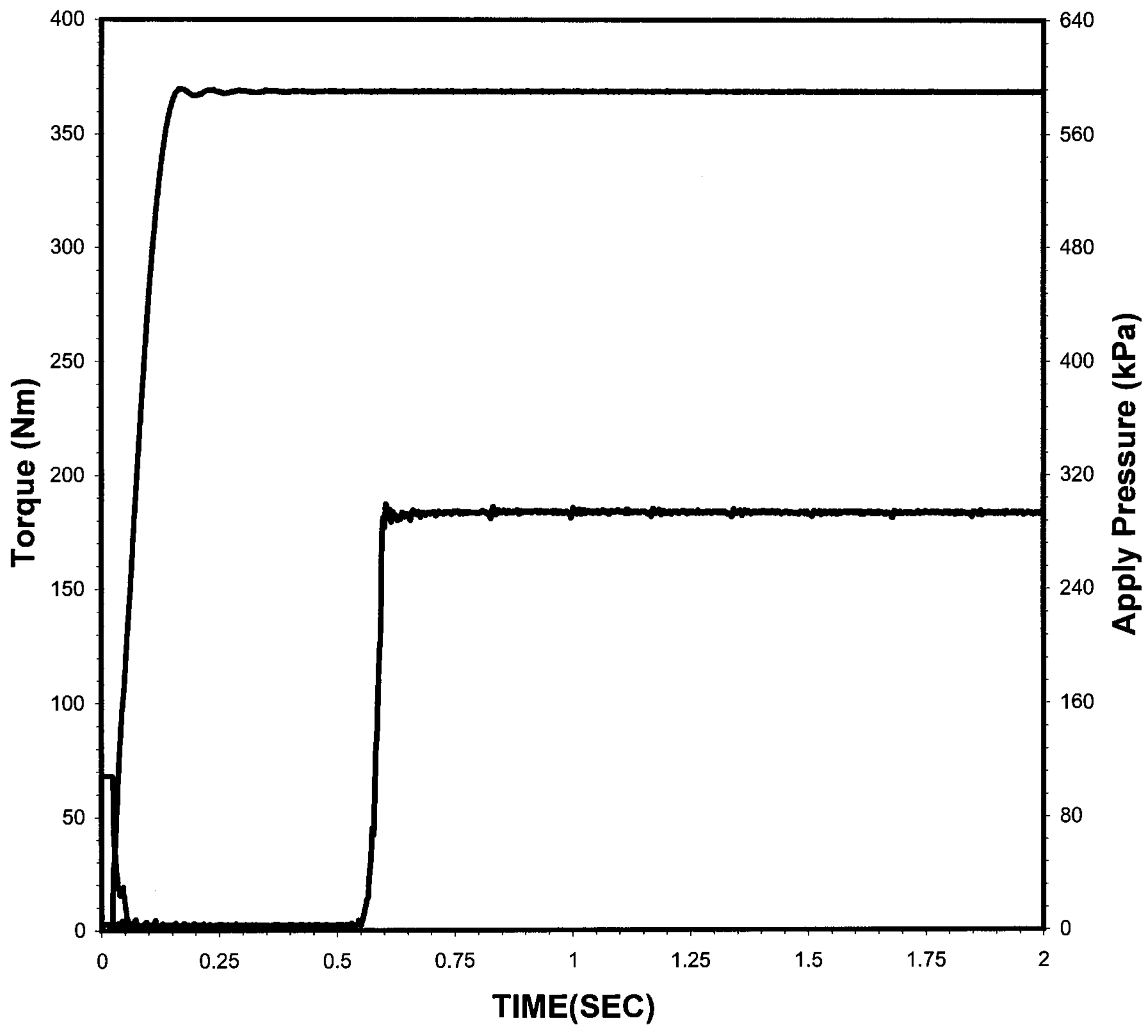
Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 292 Nm
.25 Second: 278 Nm

Coefficient of Friction
Static Peak: 0.142
.25 Second: 0.135

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/25/2010

Time of Test: 2:11:56

Test Number: C2-7-1552

Fluid Code: LO253071

Cycle Number: 10000

STATIC CYCLE

Apply Pressure:
At .25 Second: 592 kPa

Torque
Static Peak: 278 Nm
.25 Second: 270 Nm

Coefficient of Friction
Static Peak: 0.136
.25 Second: 0.132

C4 SEAL TEST SUMMARY SHEET

Test Sponsor: SOUTHWEST RESEARCH INSTITUTE

Oil Code: 253071
Secondary Code:
Test Key:
SwRI Code: 488556
Date: 20100810

Elastomer	Candidate			Average	MILPRF2104G Batch 12-06	Limits
V1 A-7-0060-85-ETI						
Volume Change, %	9.98	9.84	9.97	9.93	15.65	0.00 to 20.00
Hardness Change, pts.	-4	-3	-3	-3	-7	-15 to 0
V2 P-250						
Volume Change, %	6.80	6.39	6.02	6.40	8.08	0.00 to 12.00
Hardness Change, pts.	0	0	-1	0	-3	-7 to 3
V3 FM-L-69						
Volume Change, %	9.49	9.75	9.42	9.55	15.27	0.00 to 22.00
Hardness Change, pts.	-4	-3	-4	-4	-6	-14 to 0
P1 A-6-0160-85-ETI						
Volume Change, %	3.55	3.64	3.61	3.60	4.50	0.00 to 8.00
Hardness Change, pts.	-3	-2	-3	-3	-3	-10 to 0
P2 GR-A2256						
Volume Change, %	5.13	5.11	5.16	5.14	7.06	0.00 to 8.00
Hardness Change, pts.	0	0	0	0	-3	-11 to 3
P3 6830						
Volume Change, %	0.66	0.83	0.80	0.76	1.72	0.00 to 4.00
Hardness Change, pts.	1	1	1	1	-1	-8 to 4
F1 7V2127						
Volume Change, %	1.24	1.16	1.20	1.20	0.94	0.00 to 3.00
Hardness Change, pts.	0	0	-1	0	1	-5 to 4
F2 V150						
Volume Change, %	1.42	1.38	1.46	1.42	1.41	0.00 to 4.00
Hardness Change, pts.	0	1	1	1	1	-2 to 5
N1 GR-N1386						
Volume Change, %	-2.16	-2.15	-2.14	-2.15	0.37	0.00 to 5.00
Hardness Change, pts.	8	7	7	7	5	-12 to 12
N2						
Volume Change, %						0.00 to 6.00
Hardness Change, pts.						-9 to 5

Rebecca D. Grinfield

Rebecca D. Grinfield
Sr. Research Scientist

APPENDIX D2. – EVAULATION OF CANDIDATE LO254054 IN ALLISON C4 TRANSMISSION TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted For

ARMY LAB

Oil Code:
LO254054

Test Number:
C4-9-1287

July 23, 2010

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

VIII. Graphite Clutch Friction Test

Test Laboratory: SWRI
Test Number: C4-9-1287
Friction Plate Batch: BATCH 44
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-254054
Sponsor Fluid Code: LO254054
Completion Date: 7/23/2010

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0610	0.0587

	Before	After
Pack Clearance	0.4572	0.4826

Reference Tests

Test Number	Test Date	Test Fluid
C4-0-1257	11/25/09	PASS REF-L-06-04
C4-0-1267	01/08/10	PASS REF-L-06-04
C4-0-1278	05/26/10	PASS REF-L-06-04

	New	EOT
Viscosity at 40°C, cSt	44.19	37.56
Viscosity at 100°C, cSt	8.46	7.36
Iron Content, ppm	2	20

D5185	New Fluid (ppm)
Ba	<1
B	14
Ca	3652
Mg	12
P	1266
Si	13
Na	20
Zn	1995

Name: Matt Jackson

Signature:

Title: Manager

Date: 8/4/10

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code: **LO254054** Test Number: **C4-9-1287**

Lab Fluid Code: **254054** Fric. Plate Batch: **Batch 44**

Completion Date: **7/23/2010** Steel Plate Batch: **10/9/2008**

PHASE A

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
500	1.07	56	65	52	13	76	64
1000	1.10	55	65	46	19	75	64

PHASE B

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (0.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
1500	0.68	117	132	116	16	148	142
2000	0.68	117	133	114	19	148	142
2500	0.69	117	134	114	20	151	142
3500	0.69	116	136	111	25	150	139
4000	0.70	116	136	109	27	151	139
4500	0.70	115	135	108	27	152	138
5000	0.70	115	135	108	27	147	139
5500	0.71	114	133	106	27	148	137

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.68	0.71	4.41	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.109	0.099	-9.174	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.110	0.107	-2.727	P
Static Friction Coeff.	N/A	N/A	0.124	0.125	0.806	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.139	0.139	0.000	
0.25 Second Low Speed Coeff.	N/A	N/A	0.133	0.128	-3.759	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-GRAPHITE FRICTION TEST

Candidate Fluid: LO254054 **Test Number : C4-9-1287** **Completion Date : 7/23/2010**

Lab Fluid Code : LO-254054 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 44**

(all units in mm)

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.2510	2.1920	2.2550	2.2000	0.0590		0.0550
	120	2.2670	2.2070	2.2680	2.2090	0.0600		0.0590
	240	2.2600	2.1990	2.2610	2.2030	0.0610		0.0580
	Average					0.0600	0.0587	0.0573
STEEL SEPARATORS								
1	Top	1.7510	1.7510	1.7520	1.7520	0.0000		0.0000
	120	1.7500	1.7500	1.7500	1.7500	0.0000		0.0000
	240	1.7510	1.7510	1.7520	1.7520	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7480	1.7480	1.7470	1.7470	0.0000		0.0000
	120	1.7500	1.7500	1.7500	1.7500	0.0000		0.0000
	240	1.7490	1.7490	1.7500	1.7500	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T. (Anything Unusual) PLATES IN GOOD CONDITION WITH NO UNUSUAL DISCOLORATION. MICROMETER #0153667

Test Date: 7/23/2010

Operator's Name: MARK HOLMES

Reviewed By (Signature and Date)

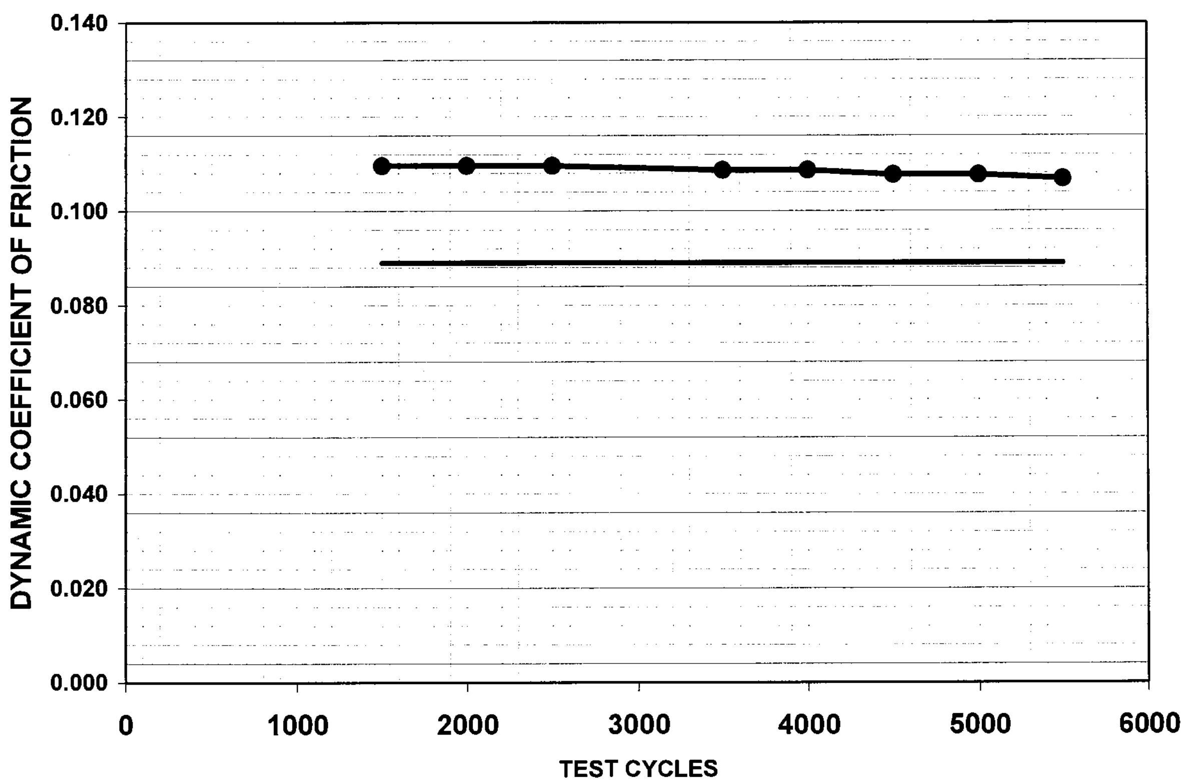
8/4/10

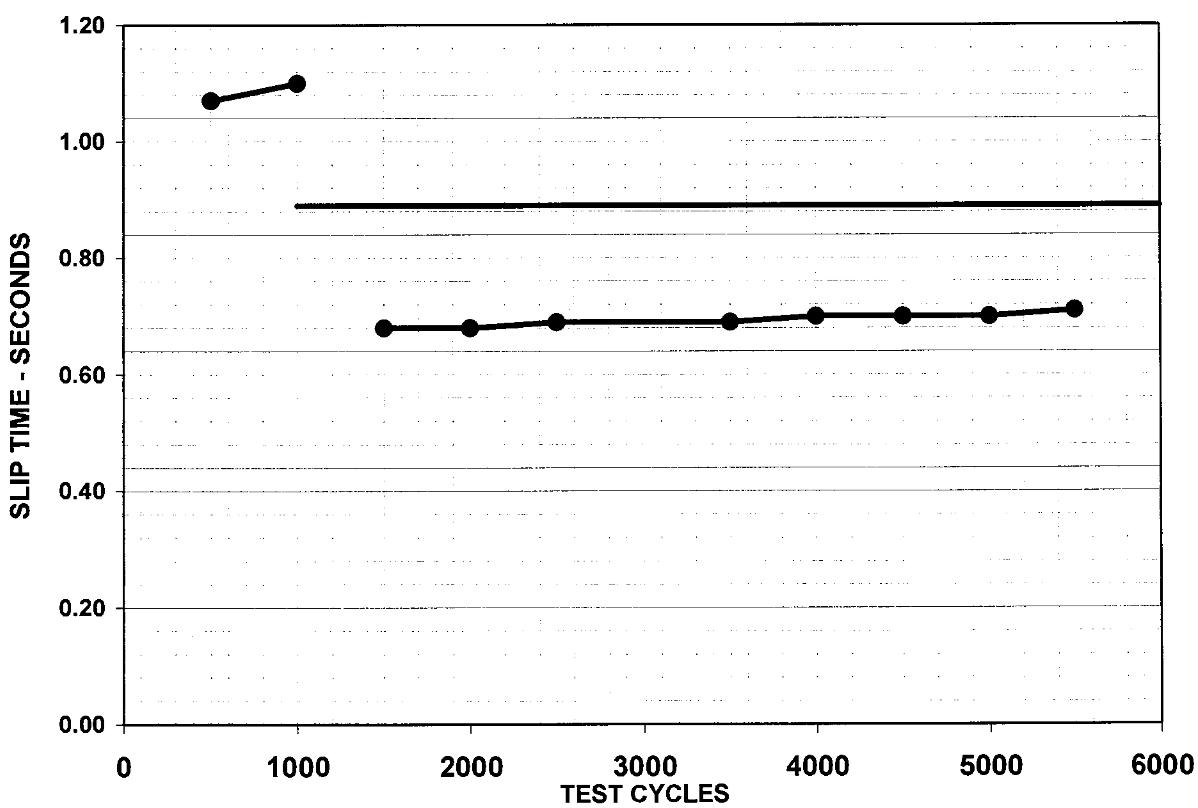
Pack ID#: 4464

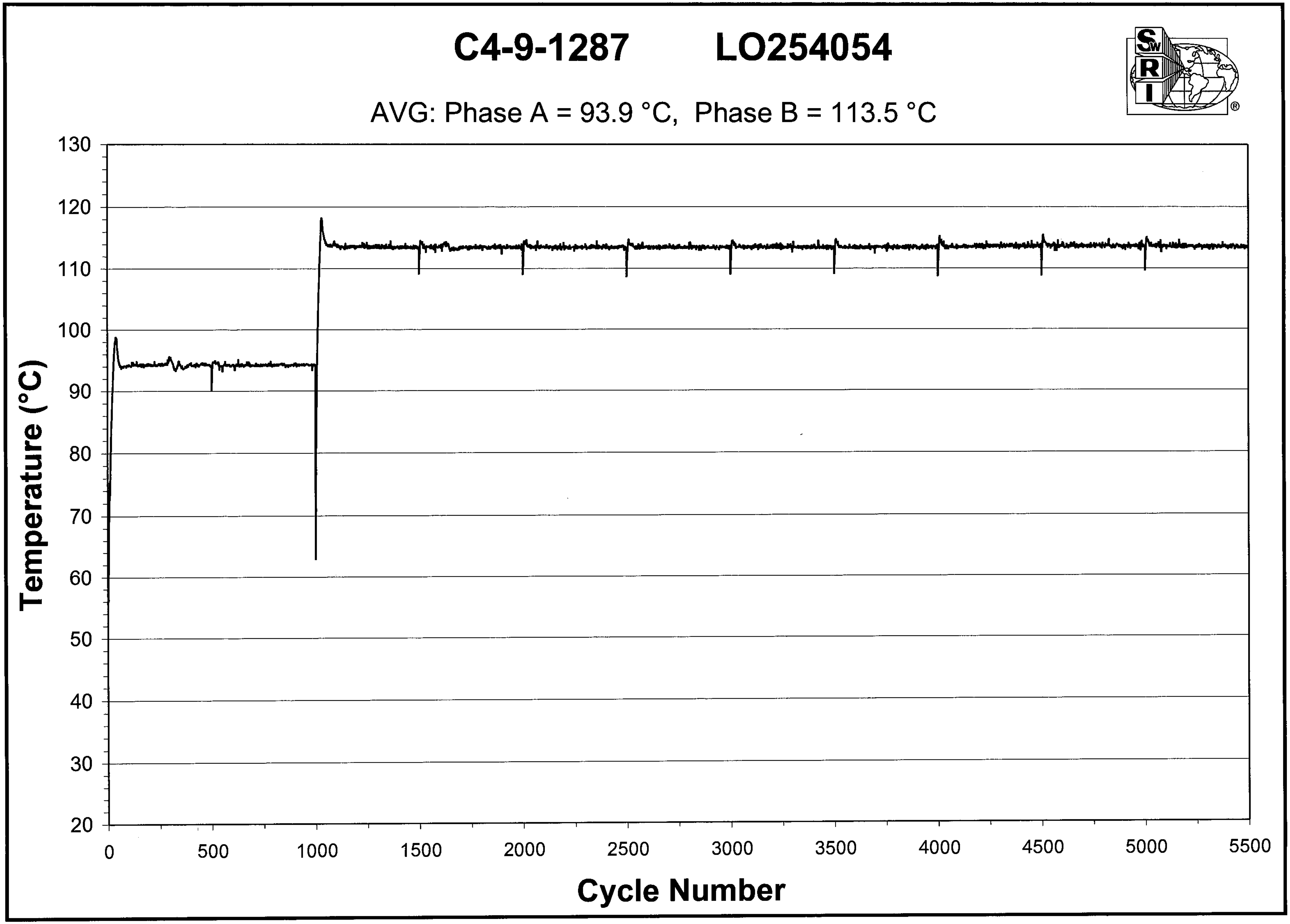
ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST

EOT Date: 7/23/2010
Test Number: C4-9-1287

Fluid Code: LO254054
Plate Batch: Batch 44
Steel Batch: 10/9/2008



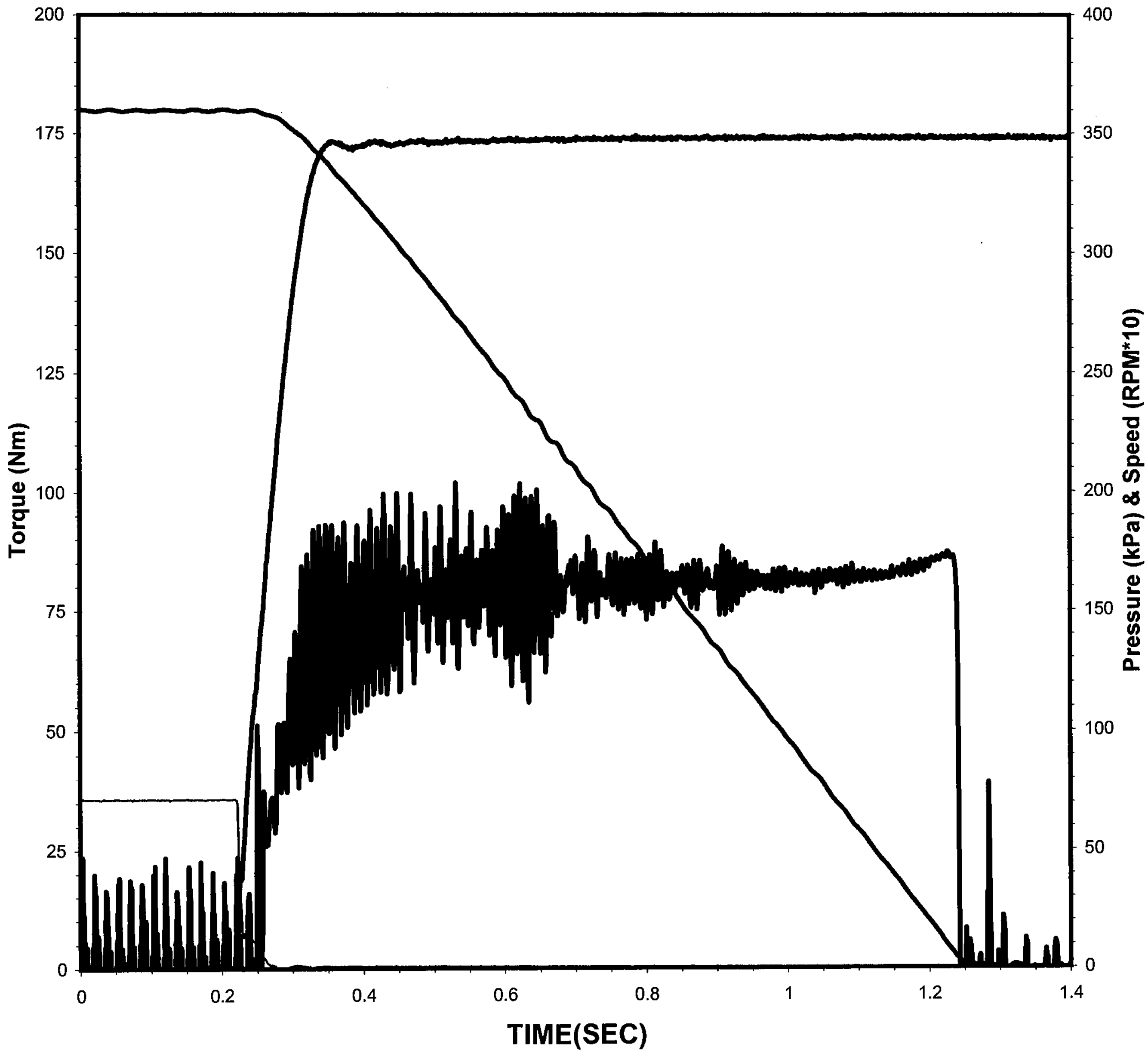



C4-9-1287 LO254054
AVG: Phase A = 93.9 °C, Phase B = 113.5 °C
Temperature (°C)
130
120
110
100
90
80
70
60
50
40
30
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Cycle Number

DYNAMIC TRACES

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/22/2010

Time of Test: 16:02:21

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 10

Temperature: 75.4 °C
(93.3 ± 3.0 °C)

Apply Pressure: 348 kPa
(345 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 14.2 KJ
(14.50 ± 0.40 KJ)

Engage Time: 1.02 Sec

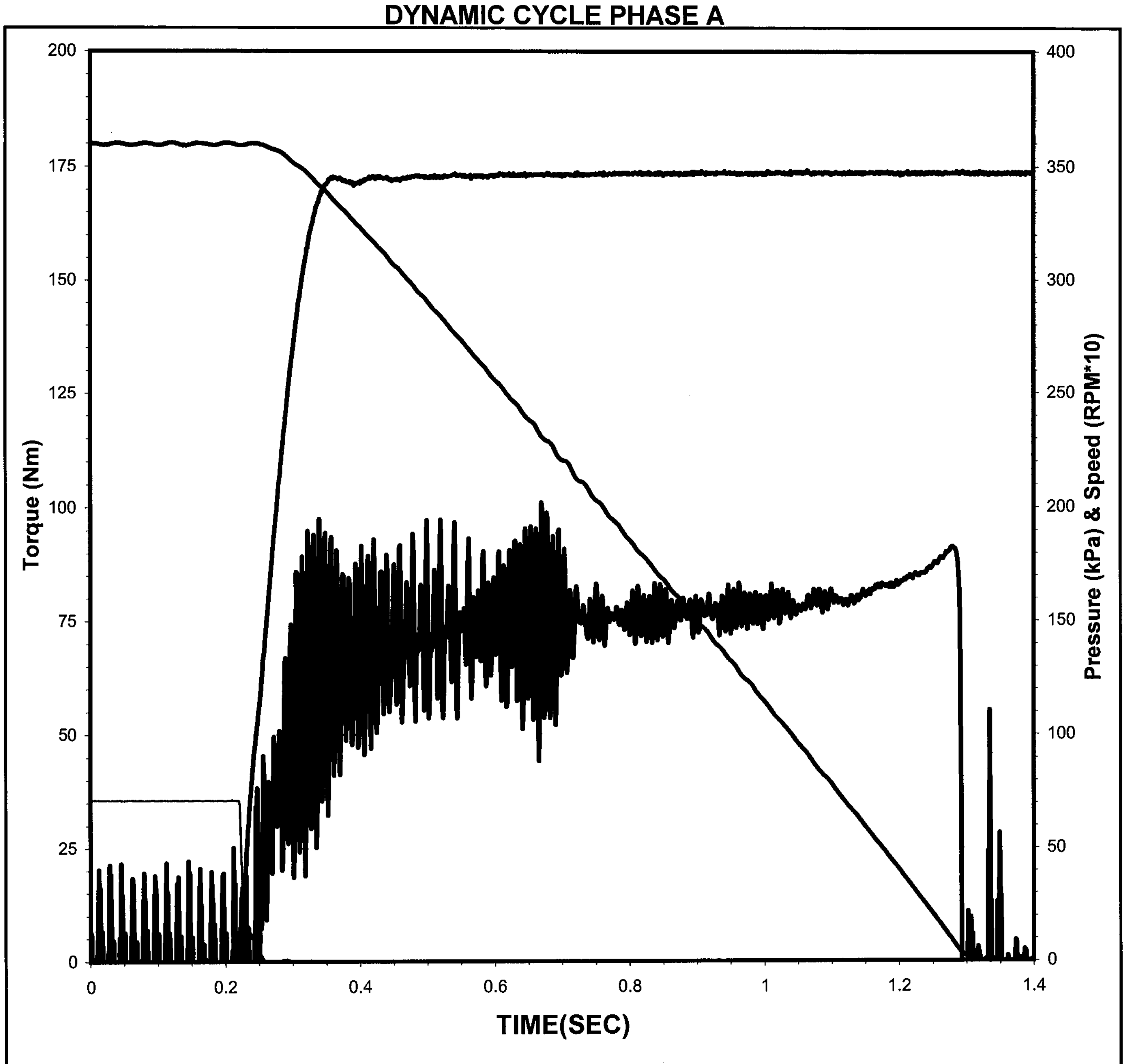
Torque

0.2 Sec Dyn:	78 N*m
Midpoint Dyn:	82 N*m
LwSpd Dynamic:	83 N*m

Coefficient of Friction

.2 Sec Dyn:	0.130
Midpoint Dyn:	0.135
LwSpd Dynamic:	0.137

ALLISON C-4 GRAPHITE DATA



Date of Test:	7/22/2010
Time of Test:	18:04:47
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	499
Temperature:	93.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	348 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.07 Sec

Torque

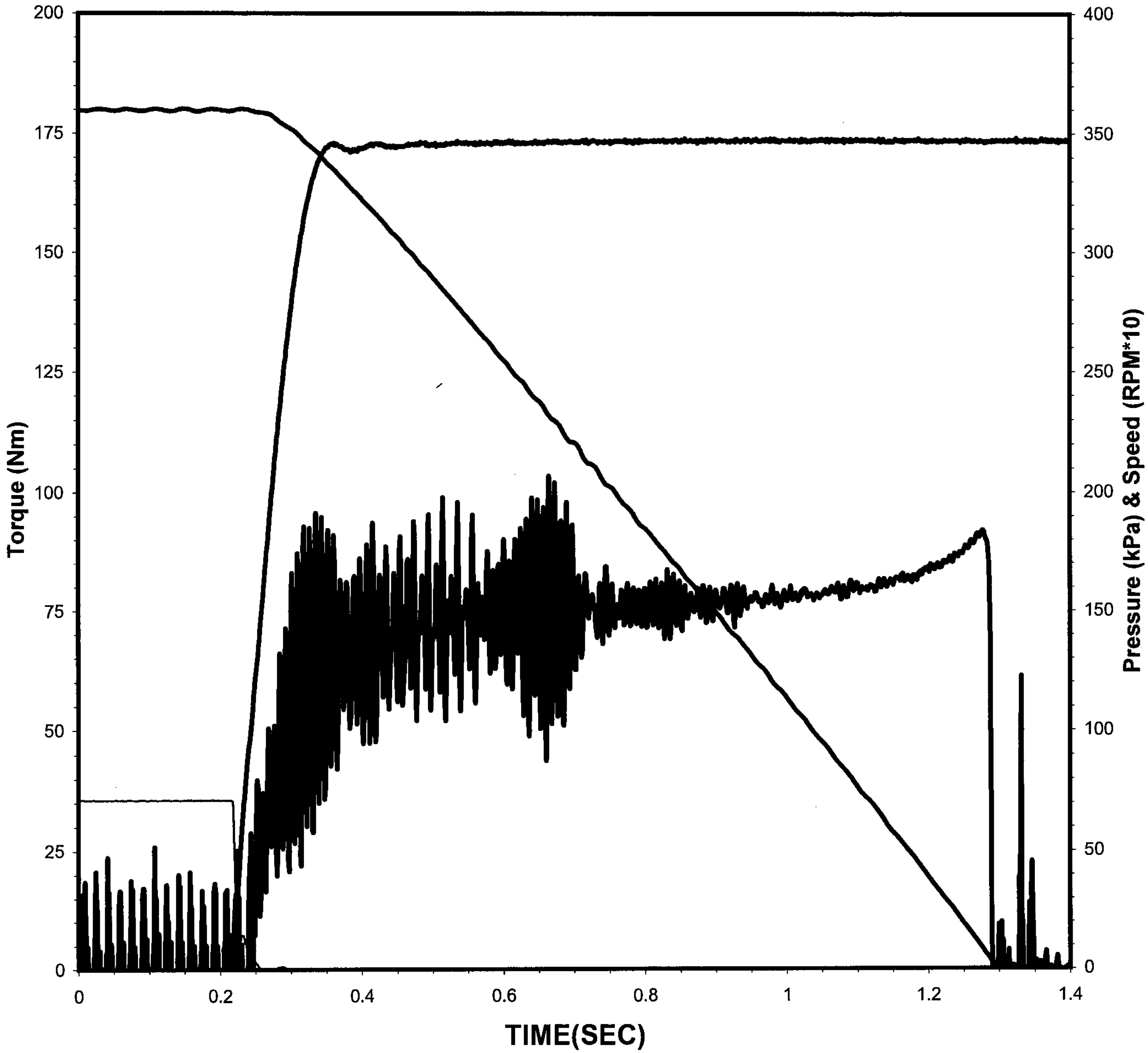
0.2 Sec Dyn:	70 N*m
Midpoint Dyn:	76 N*m
LwSpd Dynamic:	86 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.126
LwSpd Dynamic:	0.143

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	**7/22/2010**
Time of Test:	**18:05:02**
Test Number:	**C4-9-1287**
Fluid Code:	**LO254054**
Cycle Number:	**500**
Temperature:	**94.0 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**348 kPa** (345 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**14.3 KJ** (14.50 ± 0.40 KJ)
Engage Time:	**1.07 Sec**

Torque

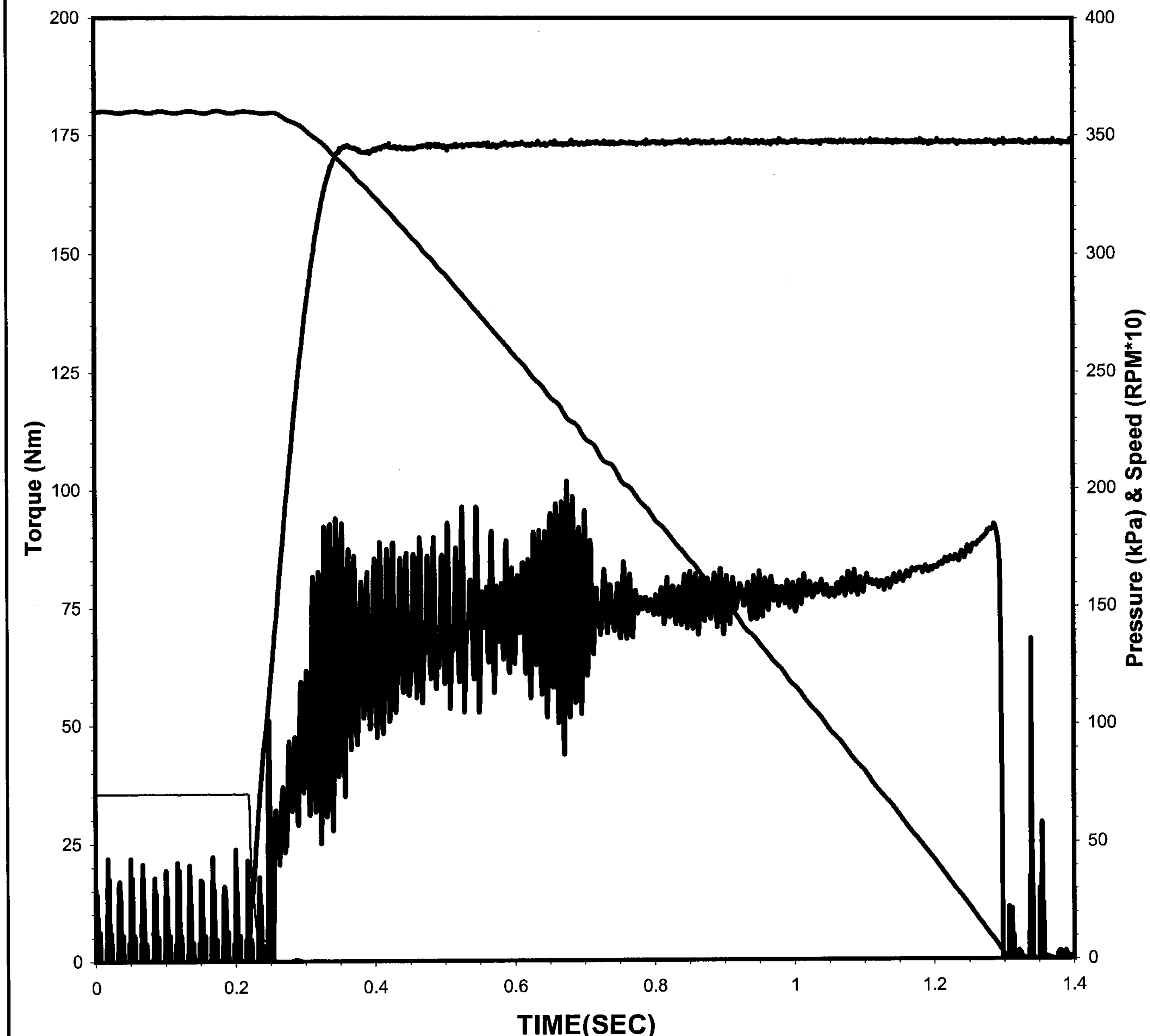
0.2 Sec Dyn:	**72 N*m**
Midpoint Dyn:	**76 N*m**
LwSpd Dynamic:	**88 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.119**
Midpoint Dyn:	**0.126**
LwSpd Dynamic:	**0.147**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/22/2010
Time of Test:	18:05:29
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	501
Temperature:	90.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	348 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.077 Sec

Torque

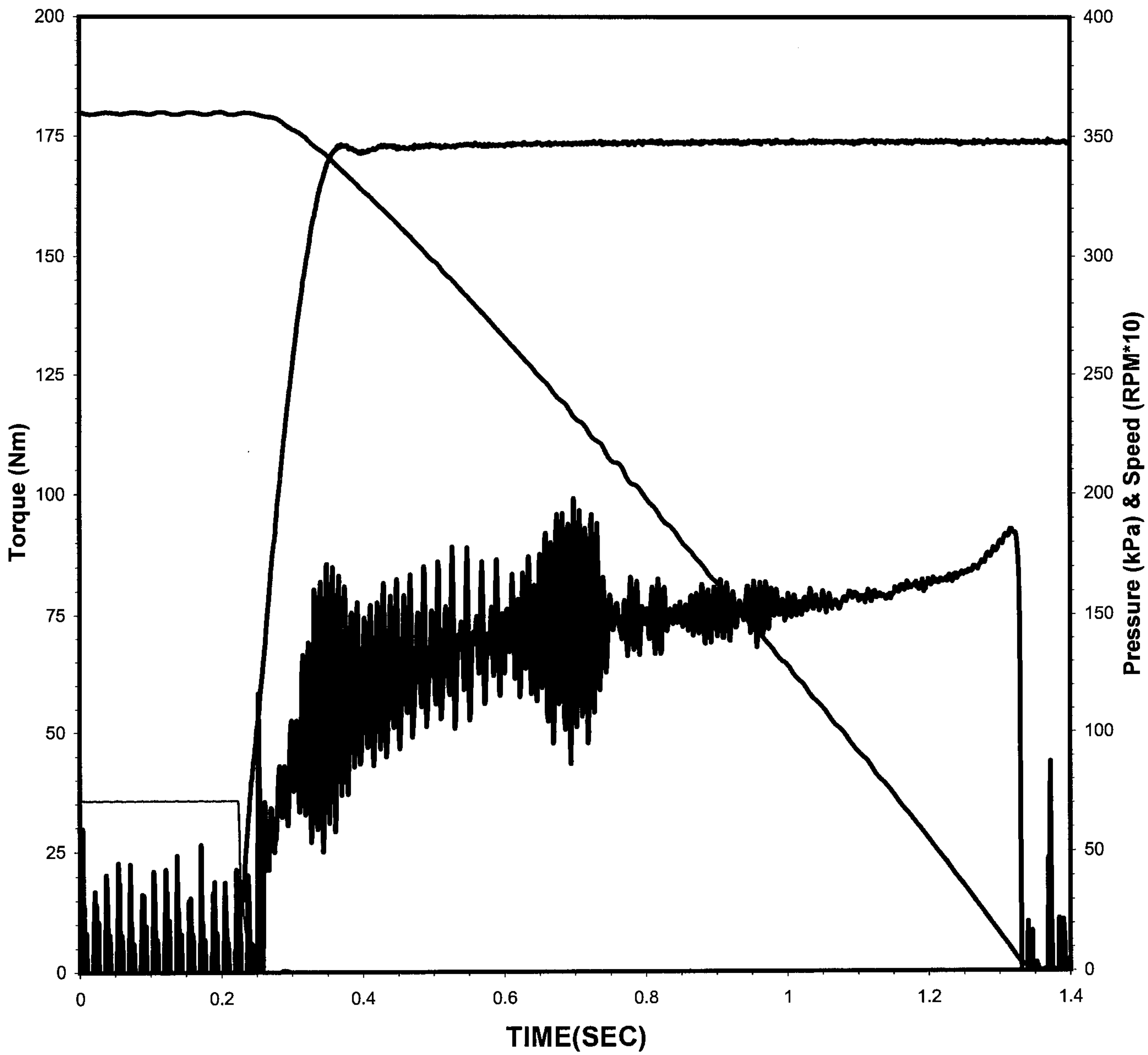
0.2 Sec Dyn:	70 N*m
Midpoint Dyn:	76 N*m
LwSpd Dynamic:	88 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.126
LwSpd Dynamic:	0.146

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/22/2010
Time of Test:	20:09:44
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	998
Temperature:	94.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	348 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.105 Sec

Torque

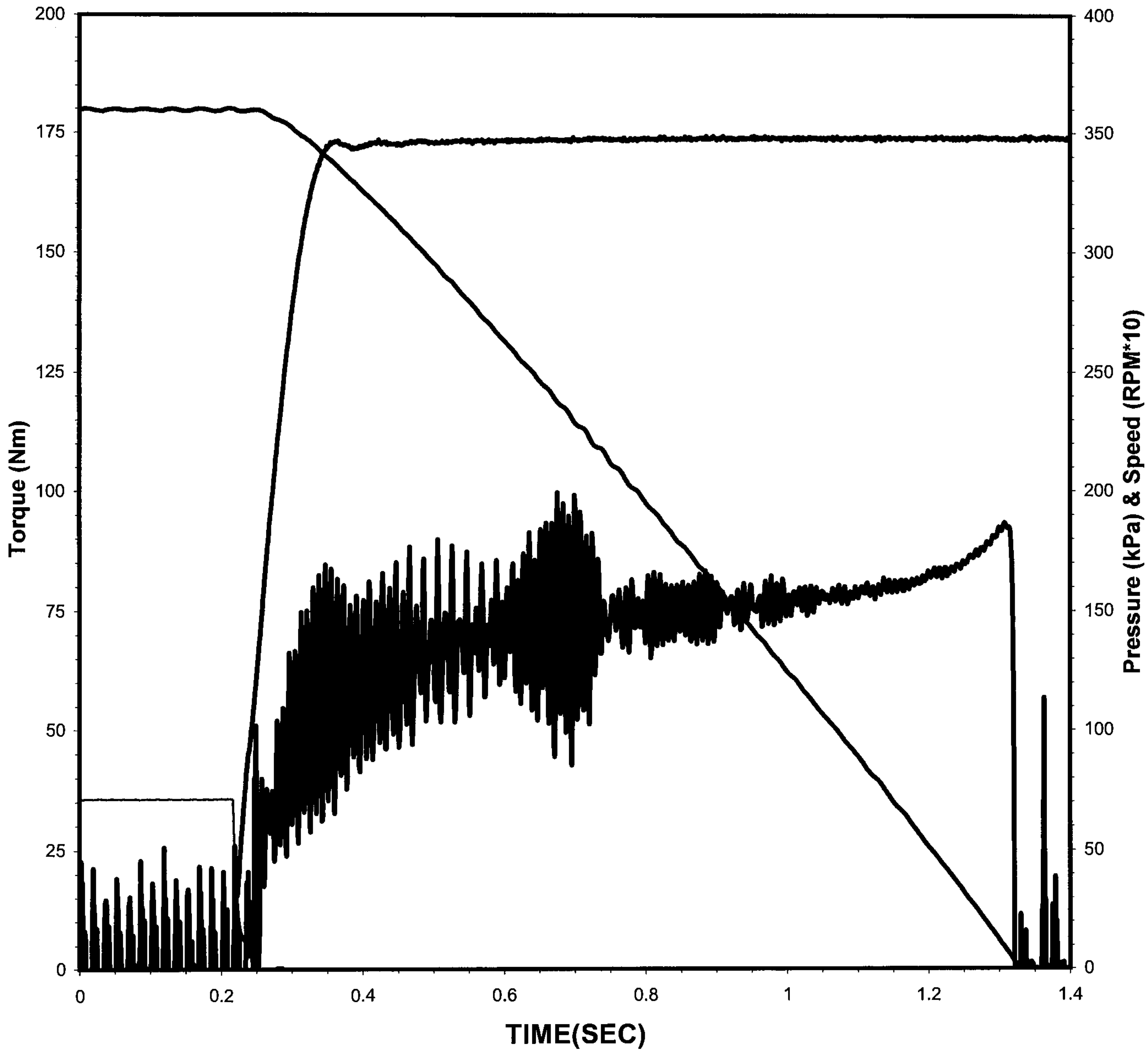
0.2 Sec Dyn:	63 N*m
Midpoint Dyn:	75 N*m
LwSpd Dynamic:	88 N*m

Coefficient of Friction

.2 Sec Dyn:	0.104
Midpoint Dyn:	0.124
LwSpd Dynamic:	0.146

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/22/2010
Time of Test:	20:09:59
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	999
Temperature:	94.1 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	348 kPa
	(345 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	14.2 KJ
	(14.50 ± 0.40 KJ)
Engage Time:	1.103 Sec

Torque

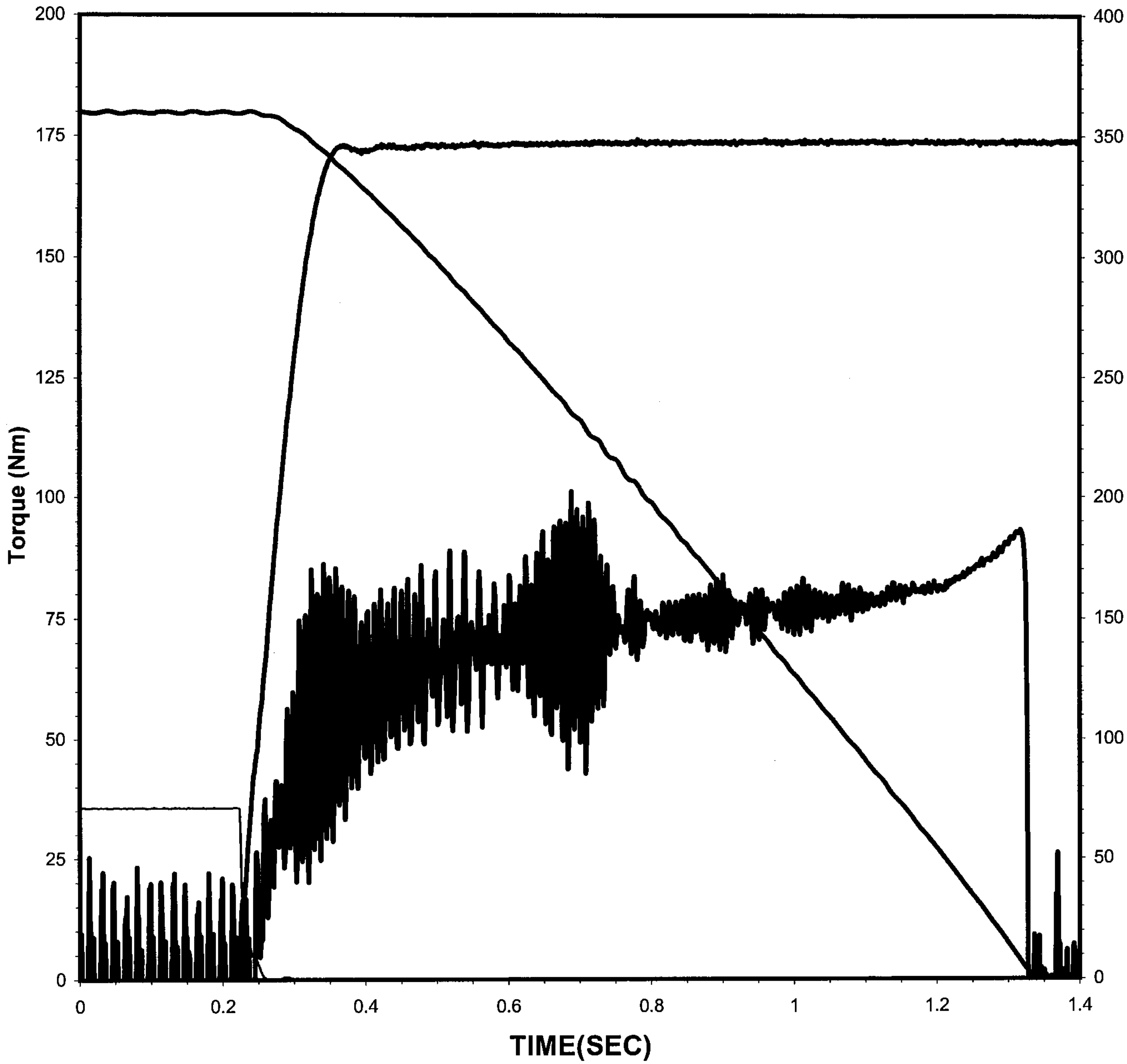
0.2 Sec Dyn:	61 N*m
Midpoint Dyn:	75 N*m
LwSpd Dynamic:	90 N*m

Coefficient of Friction

.2 Sec Dyn:	0.101
Midpoint Dyn:	0.124
LwSpd Dynamic:	0.150

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/22/2010
Time of Test:	20:10:14
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	1000
Temperature:	94.0 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	348 kPa
	(345 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	14.2 KJ
	(14.50 ± 0.40 KJ)
Engage Time:	1.103 Sec

Torque

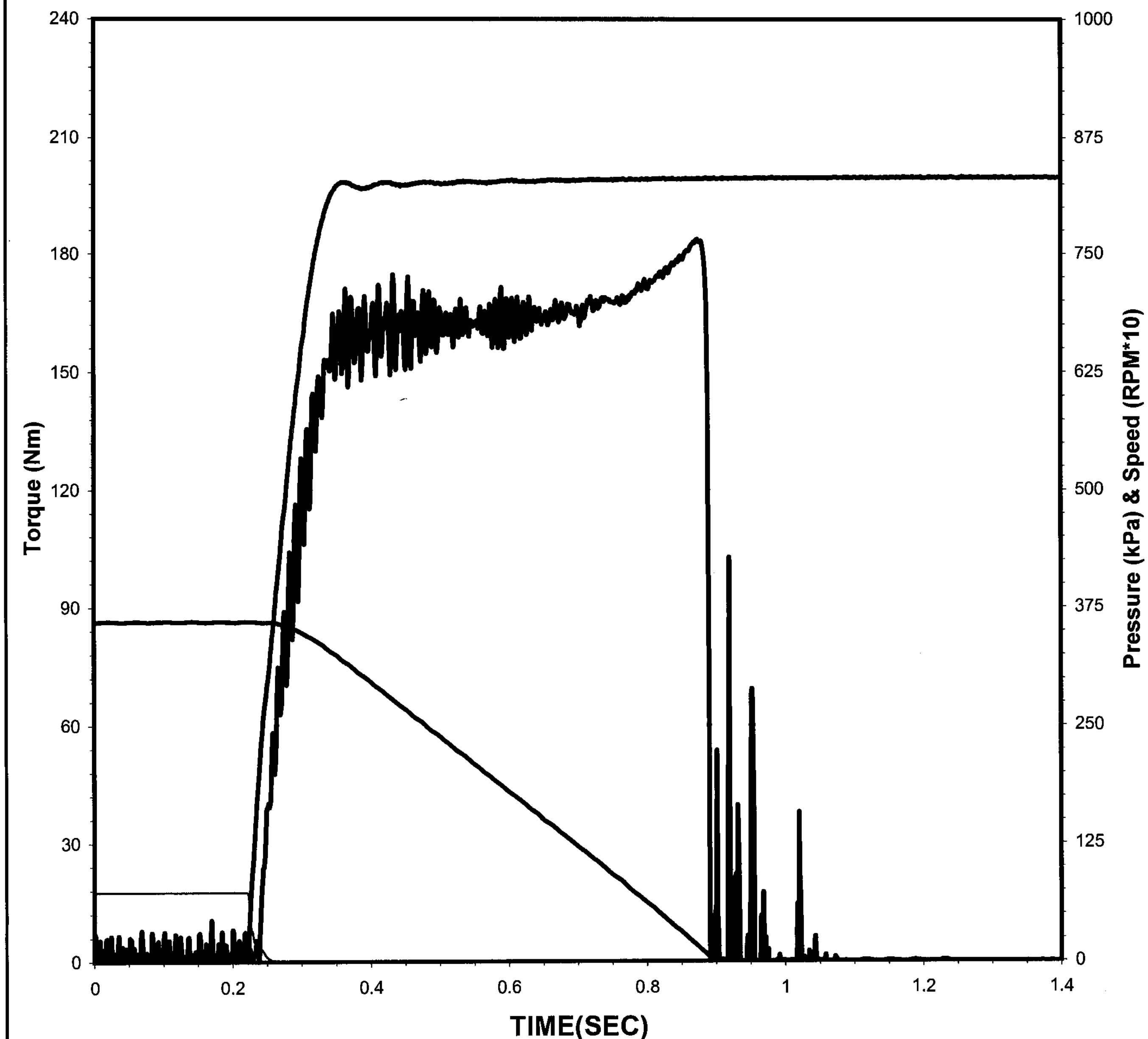
0.2 Sec Dyn:	64 N*m
Midpoint Dyn:	75 N*m
LwSpd Dynamic:	87 N*m

Coefficient of Friction

.2 Sec Dyn:	0.106
Midpoint Dyn:	0.124
LwSpd Dynamic:	0.145

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/22/2010**
Time of Test:	**20:35:59**
Test Number:	**C4-9-1287**
Fluid Code:	**LO254054**
Cycle Number:	**1010**
Temperature:	**96.1 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**827 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.668 Sec**

Torque

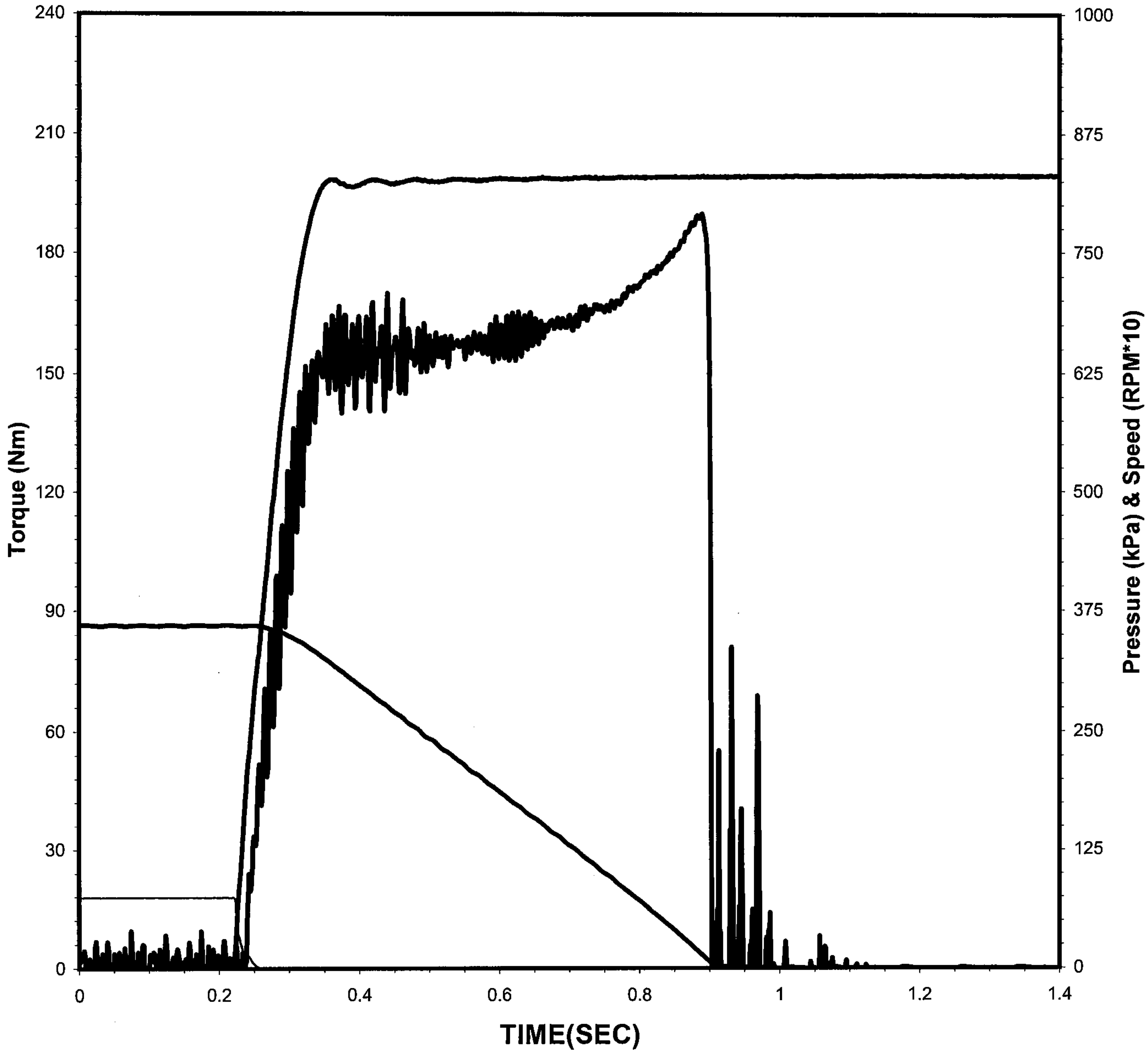
0.2 Sec Dyn:	**161 N*m**
Midpoint Dyn:	**163 N*m**
LwSpd Dynamic:	**173 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.111**
Midpoint Dyn:	**0.113**
LwSpd Dynamic:	**0.120**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/22/2010

Time of Test: 22:38:14

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 1499

Temperature: 113.5 °C
(112.7 ± 3.0 °C)

Apply Pressure: 828 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.68 Sec

Torque

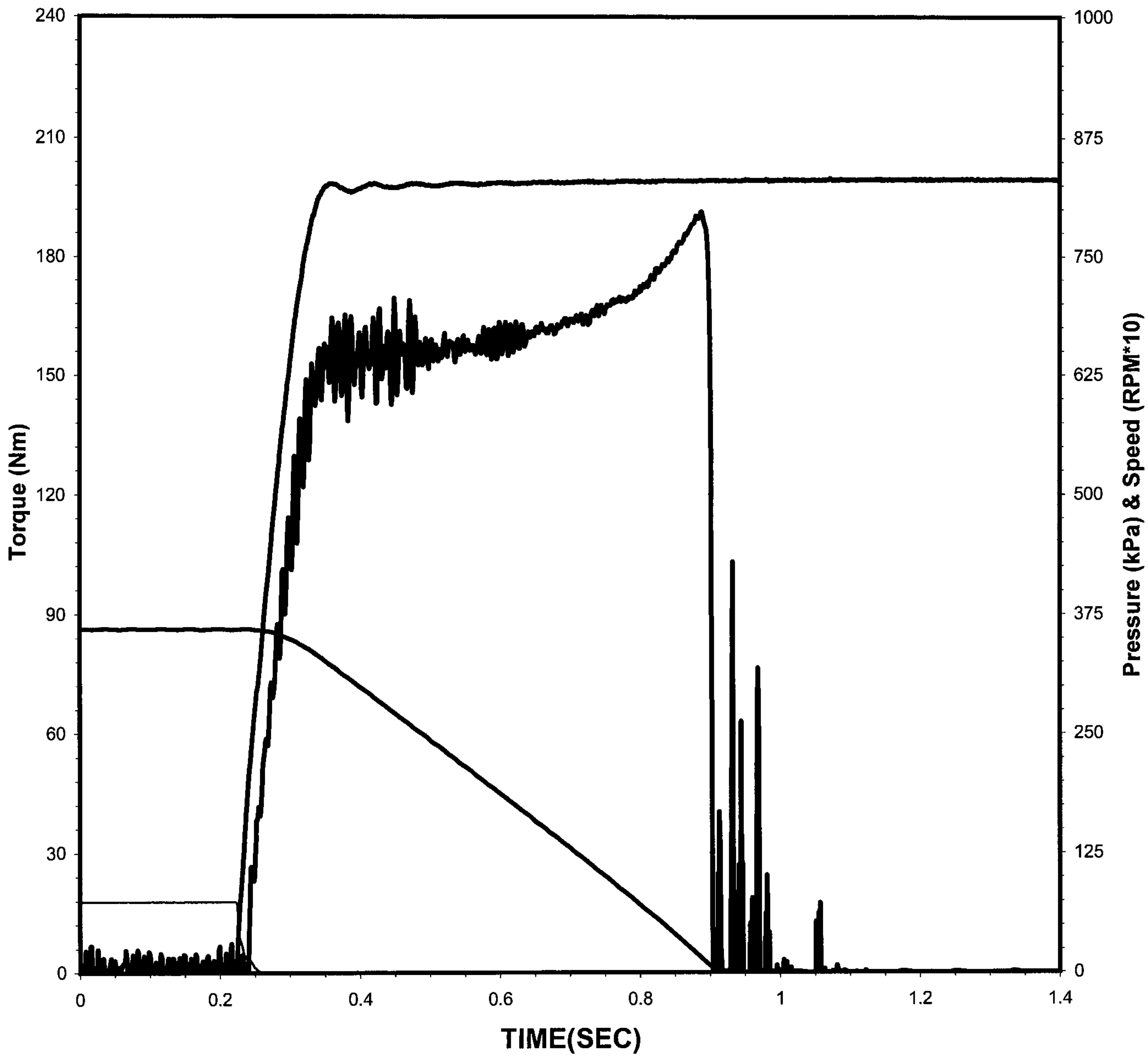
0.2 Sec Dyn:	158 N*m
Midpoint Dyn:	158 N*m
LwSpd Dynamic:	178 N*m

Coefficient of Friction

.2 Sec Dyn:	0.109
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.123

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/22/2010
Time of Test:	22:38:29
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	1500
Temperature:	113.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	828 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.68 Sec

Torque

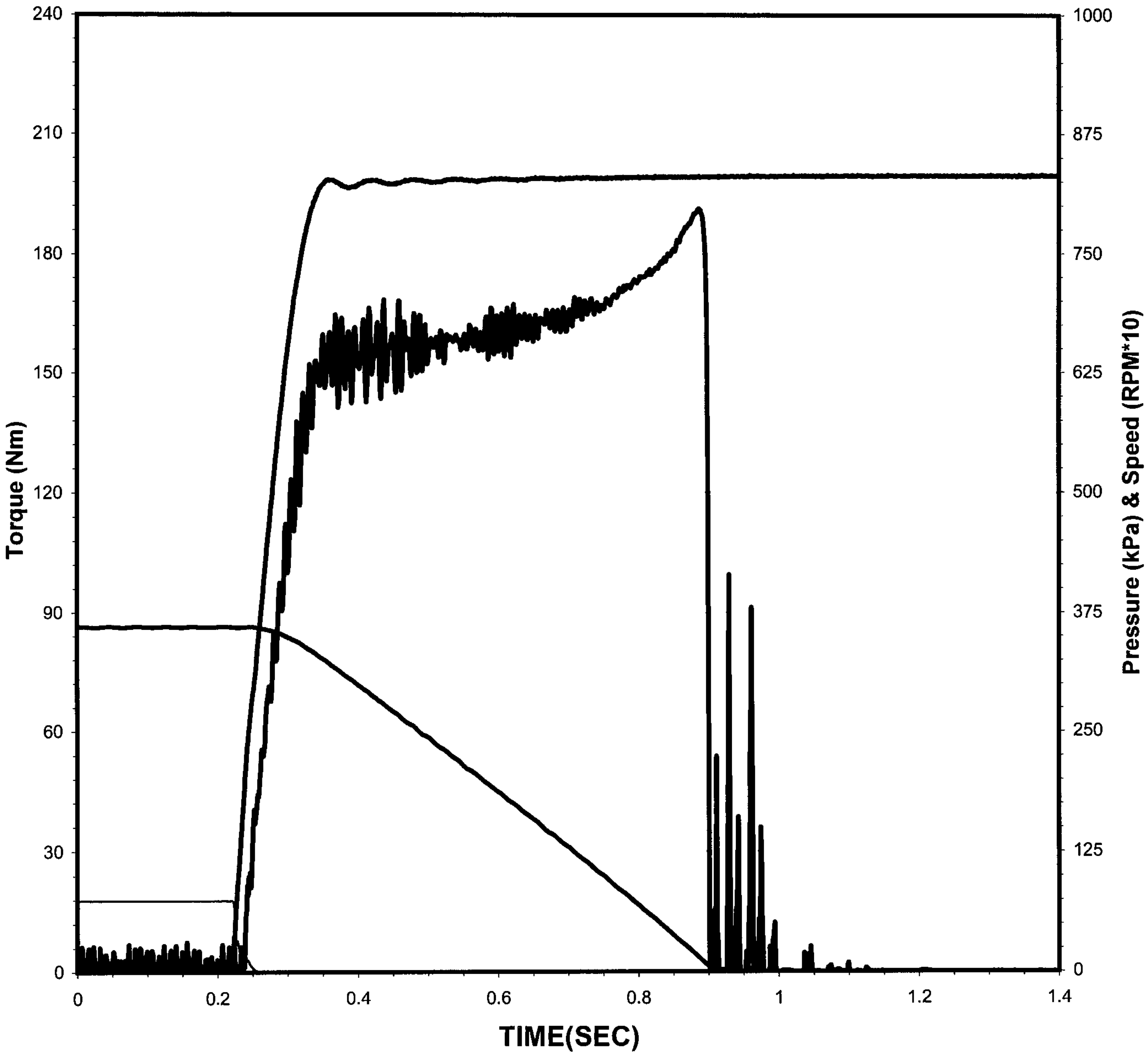
0.2 Sec Dyn:	156 N*m
Midpoint Dyn:	159 N*m
LwSpd Dynamic:	180 N*m

Coefficient of Friction

.2 Sec Dyn:	0.108
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/22/2010

Time of Test: 22:38:55

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 1501

Temperature: 109.1 °C
(112.7 ± 3.0 °C)

Apply Pressure: 828 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.679 Sec

Torque

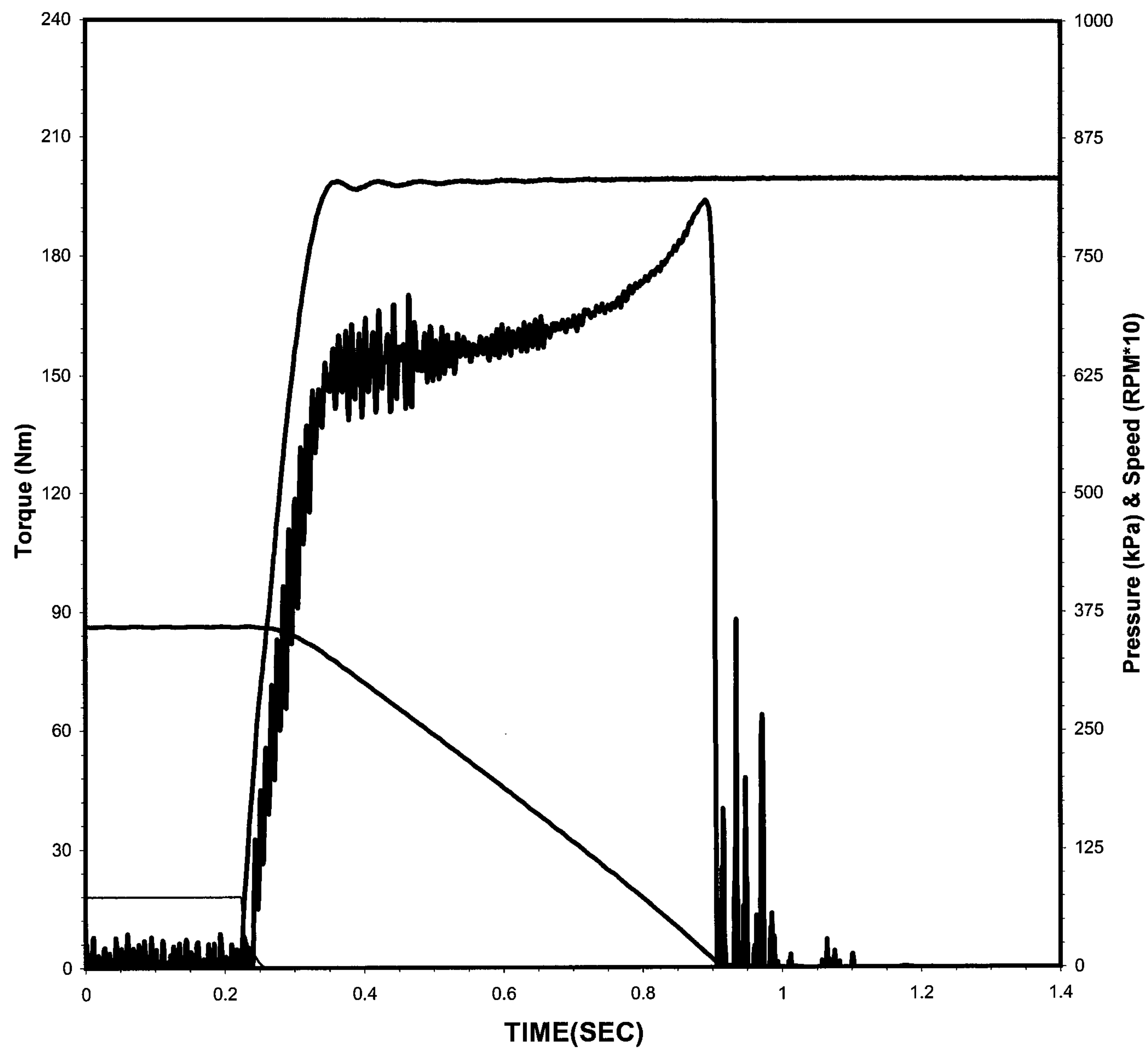
0.2 Sec Dyn:	158 N*m
Midpoint Dyn:	159 N*m
LwSpd Dynamic:	180 N*m

Coefficient of Friction

.2 Sec Dyn:	0.109
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	0:43:25
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	1999
Temperature:	114.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.683 Sec

Torque

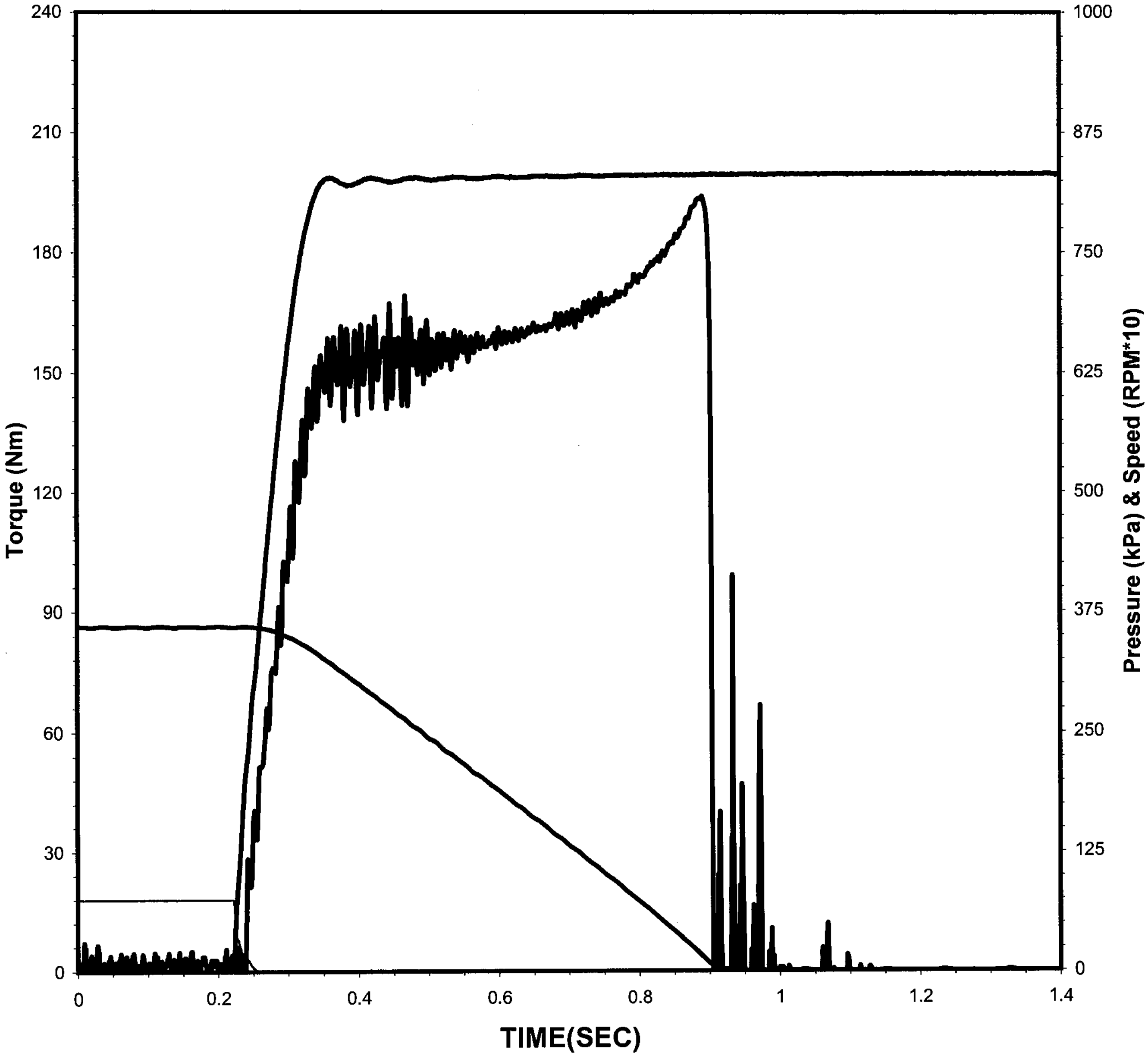
0.2 Sec Dyn:	154 N*m
Midpoint Dyn:	158 N*m
LwSpd Dynamic:	179 N*m

Coefficient of Friction

.2 Sec Dyn:	0.106
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.124

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	0:43:41
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	2000
Temperature:	113.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.683 Sec

Torque

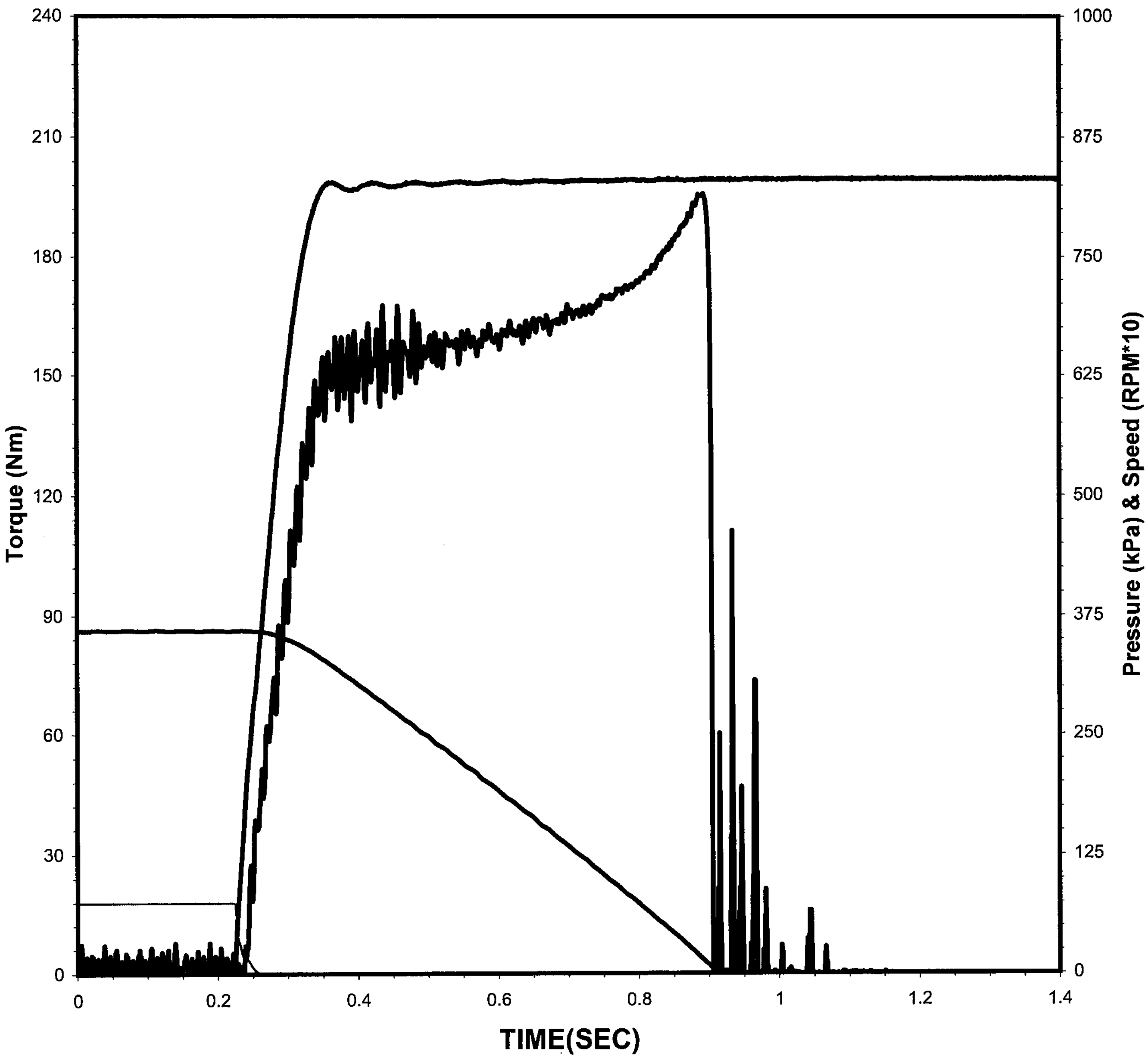
0.2 Sec Dyn:	154 N*m
Midpoint Dyn:	158 N*m
LwSpd Dynamic:	179 N*m

Coefficient of Friction

.2 Sec Dyn:	0.107
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.124

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/23/2010

Time of Test: 0:44:07

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 2001

Temperature: 109.0 °C
(112.7 ± 3.0 °C)

Apply Pressure: 829 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.681 Sec

Torque

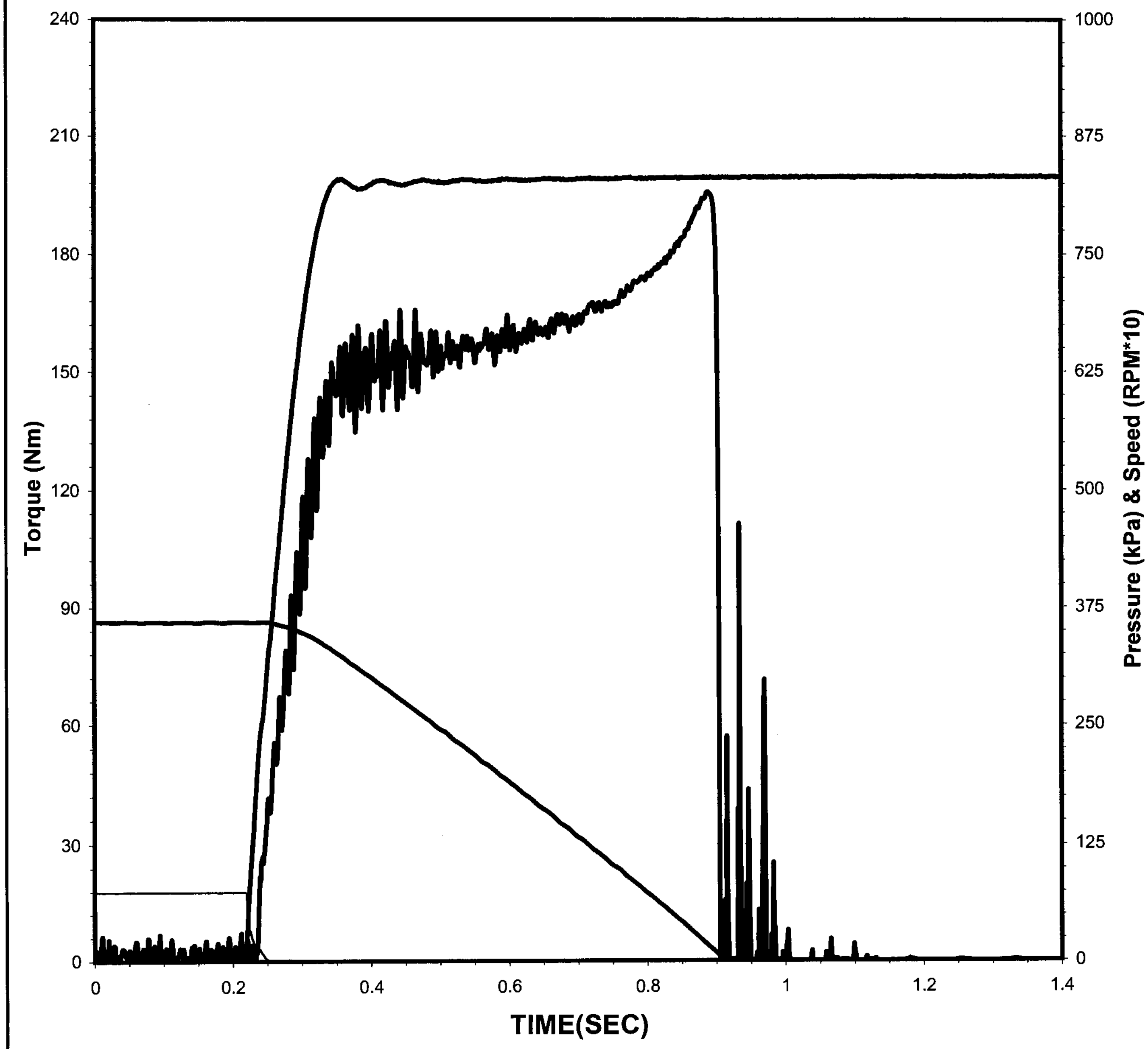
0.2 Sec Dyn: 154 N*m
Midpoint Dyn: 159 N*m
LwSpd Dynamic: 181 N*m

Coefficient of Friction

.2 Sec Dyn: 0.106
Midpoint Dyn: 0.110
LwSpd Dynamic: 0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	2:48:37
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	2499
Temperature:	113.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.686 Sec

Torque

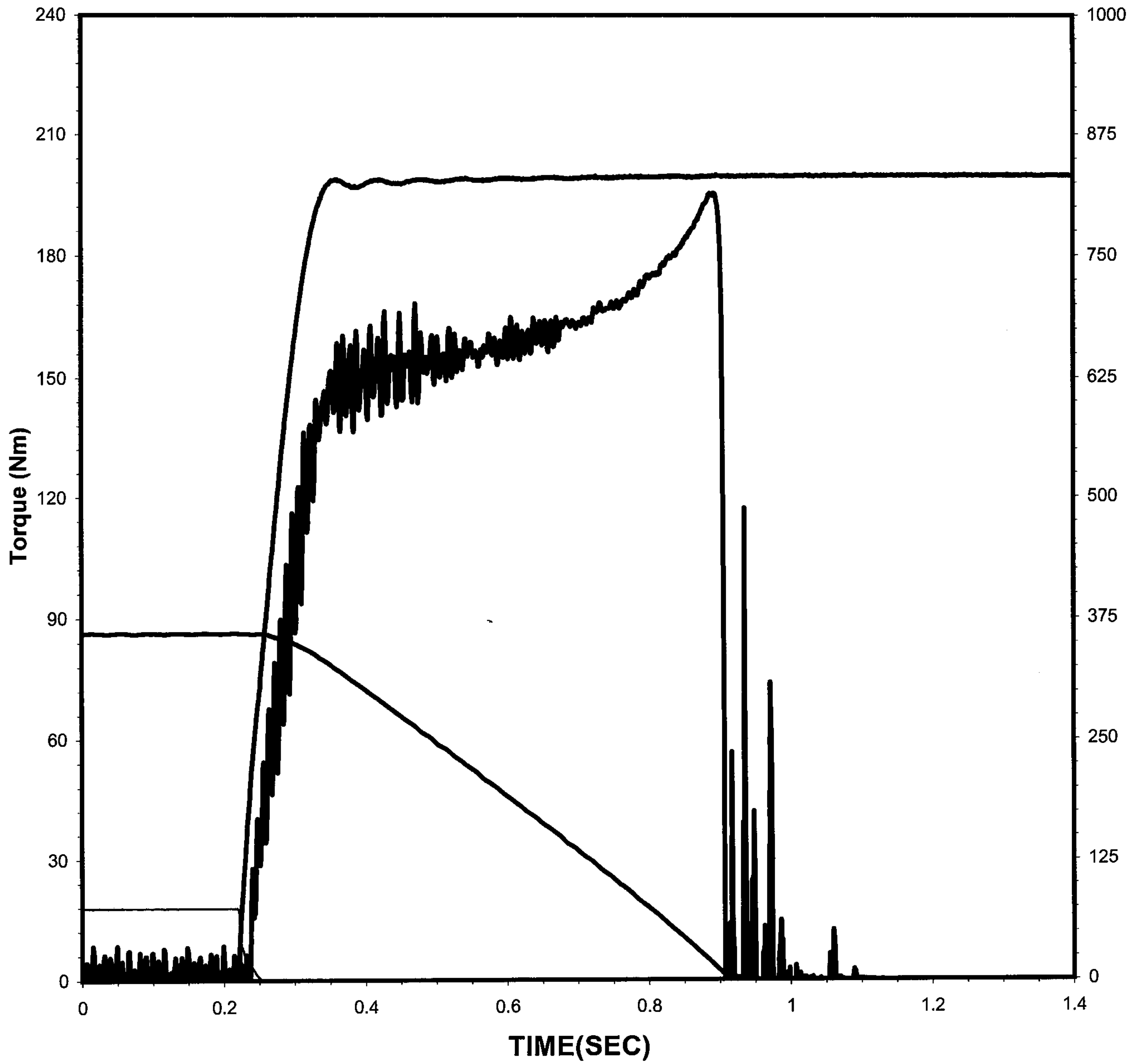
0.2 Sec Dyn:	153 N*m
Midpoint Dyn:	157 N*m
LwSpd Dynamic:	183 N*m

Coefficient of Friction

.2 Sec Dyn:	0.106
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	2:48:52
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	2500
Temperature:	113.3 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.686 Sec

Torque

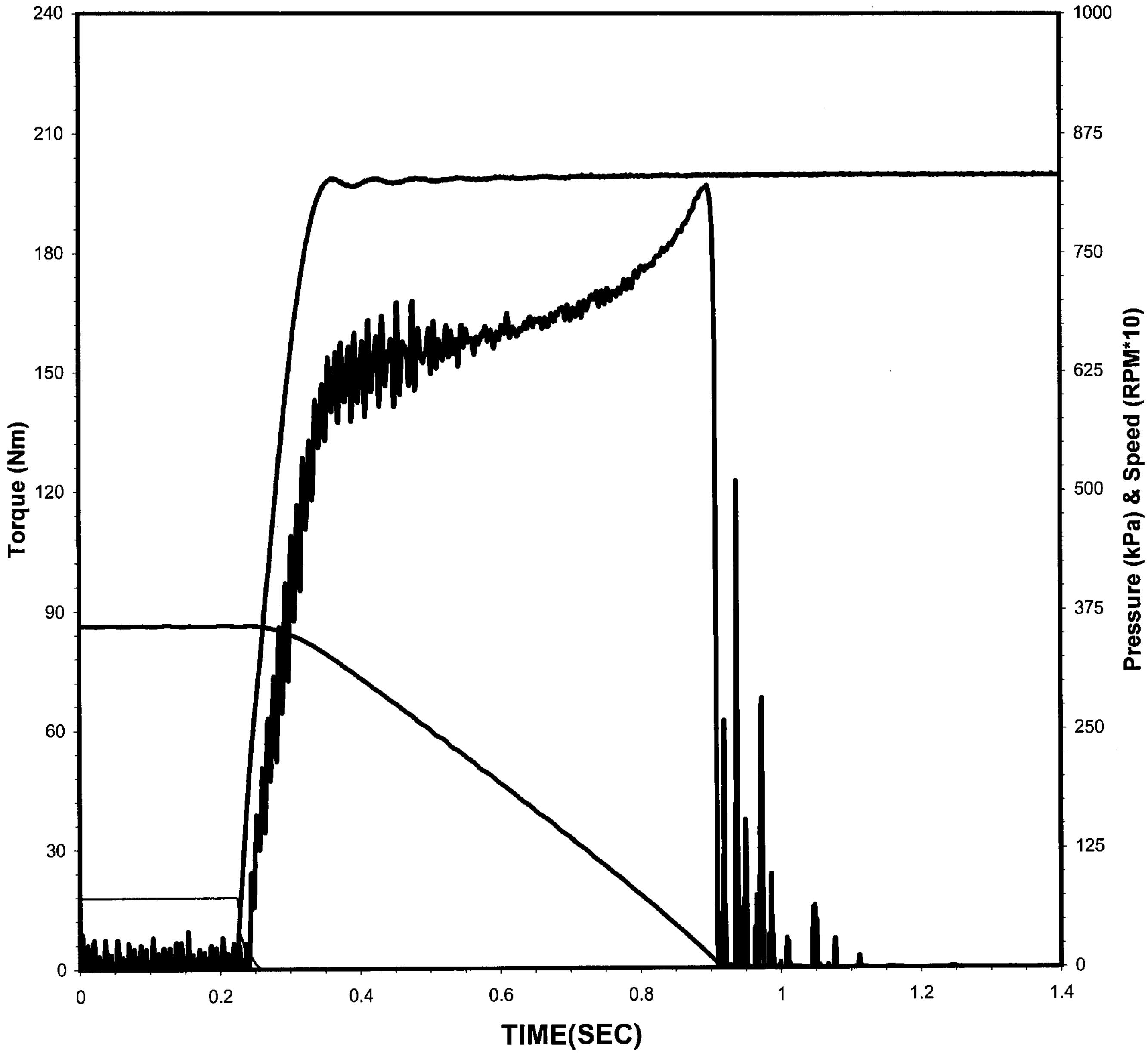
0.2 Sec Dyn:	154 N*m
Midpoint Dyn:	158 N*m
LwSpd Dynamic:	183 N*m

Coefficient of Friction

.2 Sec Dyn:	0.107
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/23/2010

Time of Test: 2:49:19

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 2501

Temperature: 108.6 °C
(112.7 ± 3.0 °C)

Apply Pressure: 829 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.685 Sec

Torque

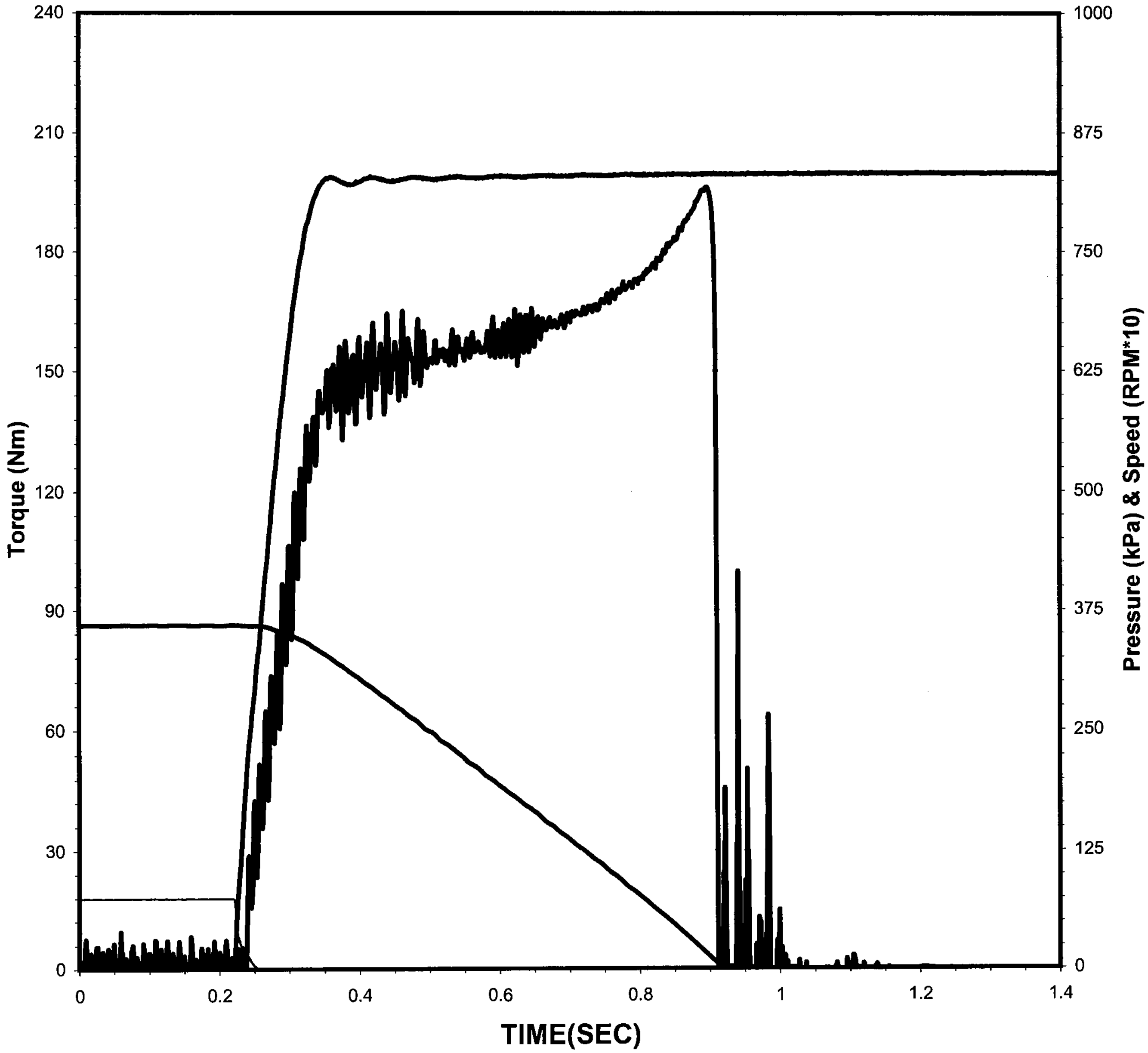
0.2 Sec Dyn:	**155 N*m**
Midpoint Dyn:	**159 N*m**
LwSpd Dynamic:	**182 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.107**
Midpoint Dyn:	**0.110**
LwSpd Dynamic:	**0.126**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/23/2010

Time of Test: 4:53:49

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 2999

Temperature: 113.4 °C
(112.7 ± 3.0 °C)

Apply Pressure: 829 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.69 Sec

Torque

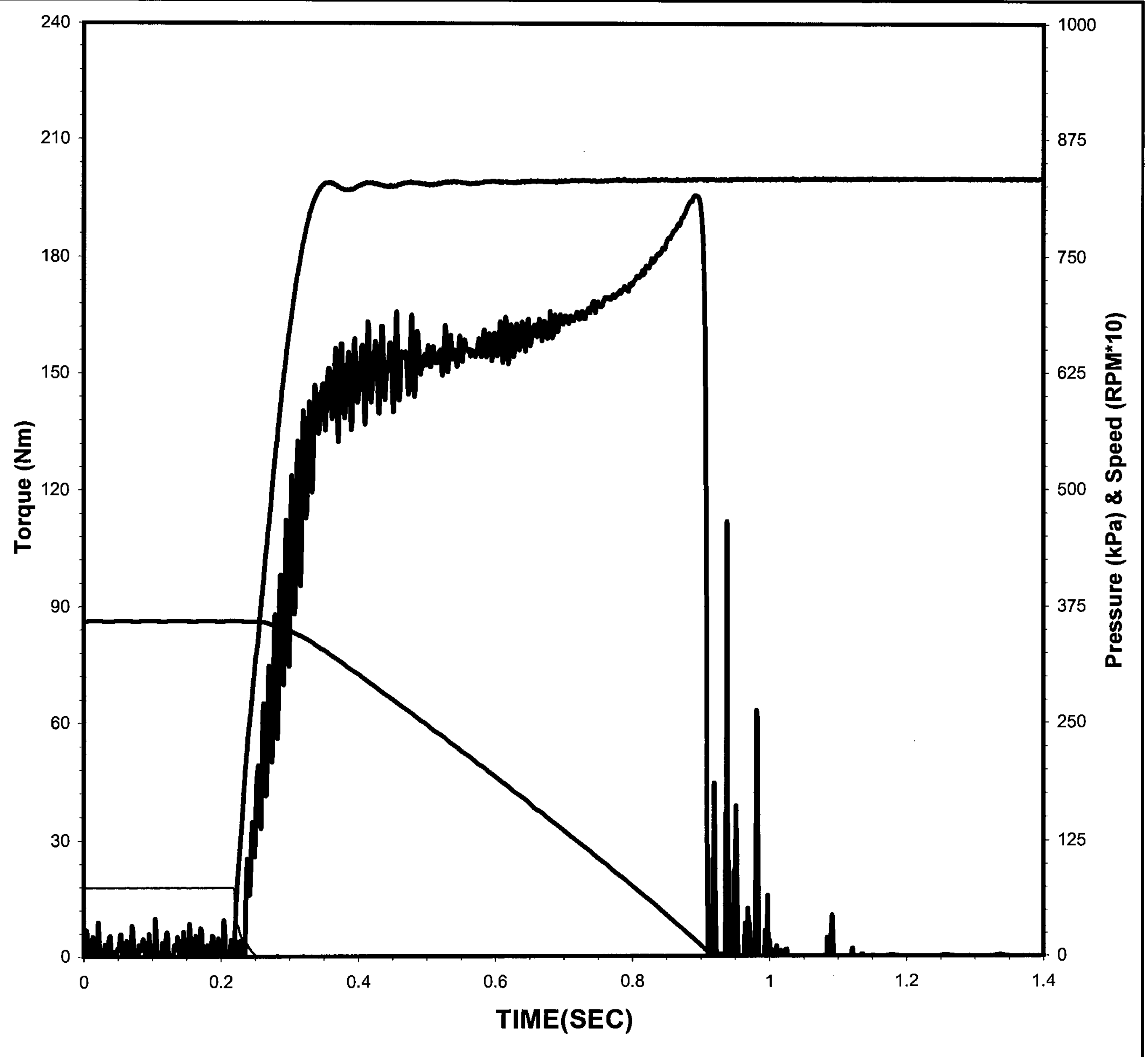
0.2 Sec Dyn:	152 N*m
Midpoint Dyn:	157 N*m
LwSpd Dynamic:	184 N*m

Coefficient of Friction

.2 Sec Dyn:	0.105
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/23/2010

Time of Test: 4:54:04

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 3000

Temperature: 113.6 °C
(112.7 ± 3.0 °C)

Apply Pressure: 829 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.691 Sec

Torque

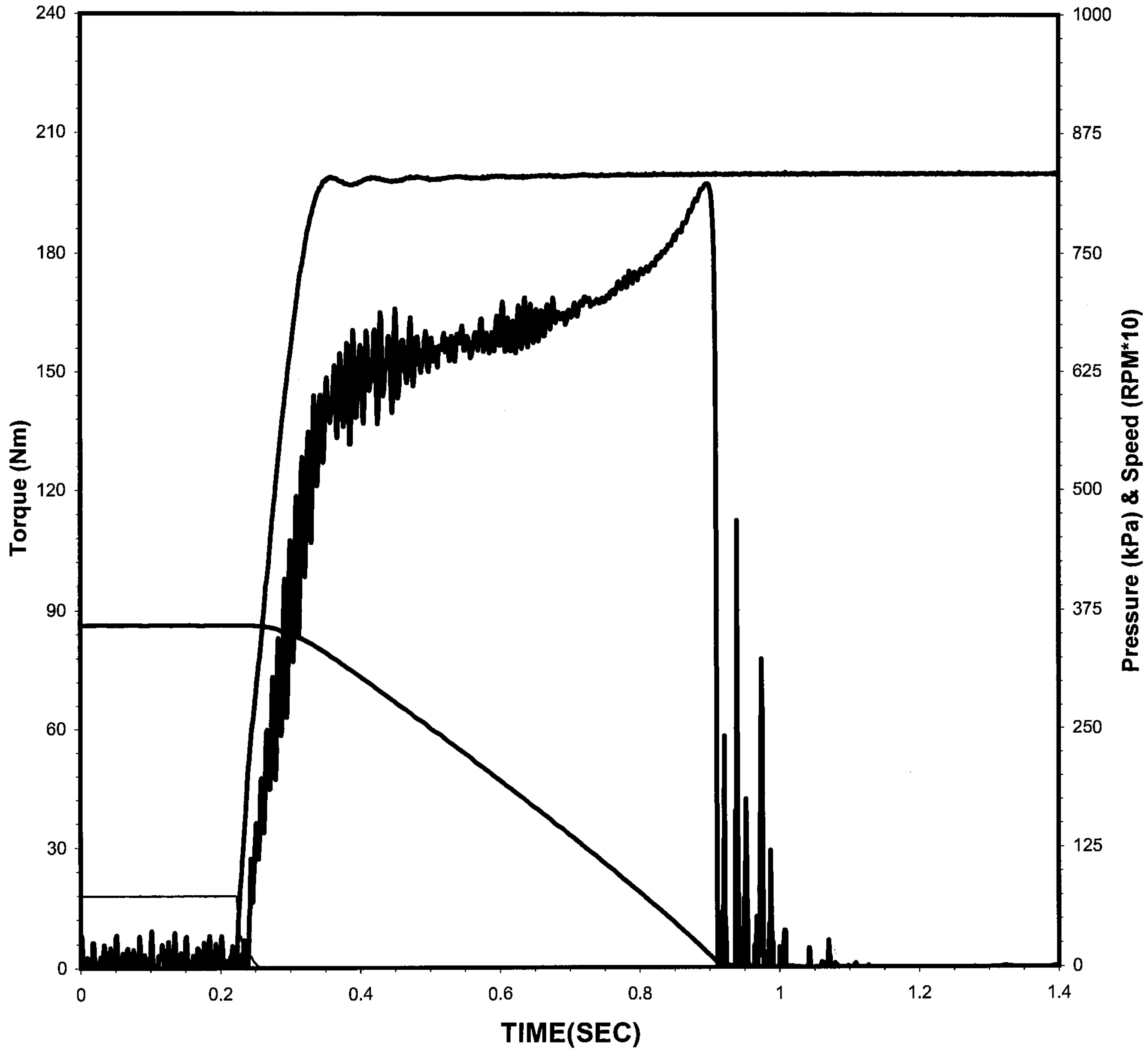
0.2 Sec Dyn: 153 N*m
Midpoint Dyn: 157 N*m
LwSpd Dynamic: 179 N*m

Coefficient of Friction

.2 Sec Dyn: 0.106
Midpoint Dyn: 0.108
LwSpd Dynamic: 0.124

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/23/2010**
Time of Test:	**4:54:31**
Test Number:	**C4-9-1287**
Fluid Code:	**LO254054**
Cycle Number:	**3001**
Temperature:	**109.0 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**829 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.688 Sec**

Torque

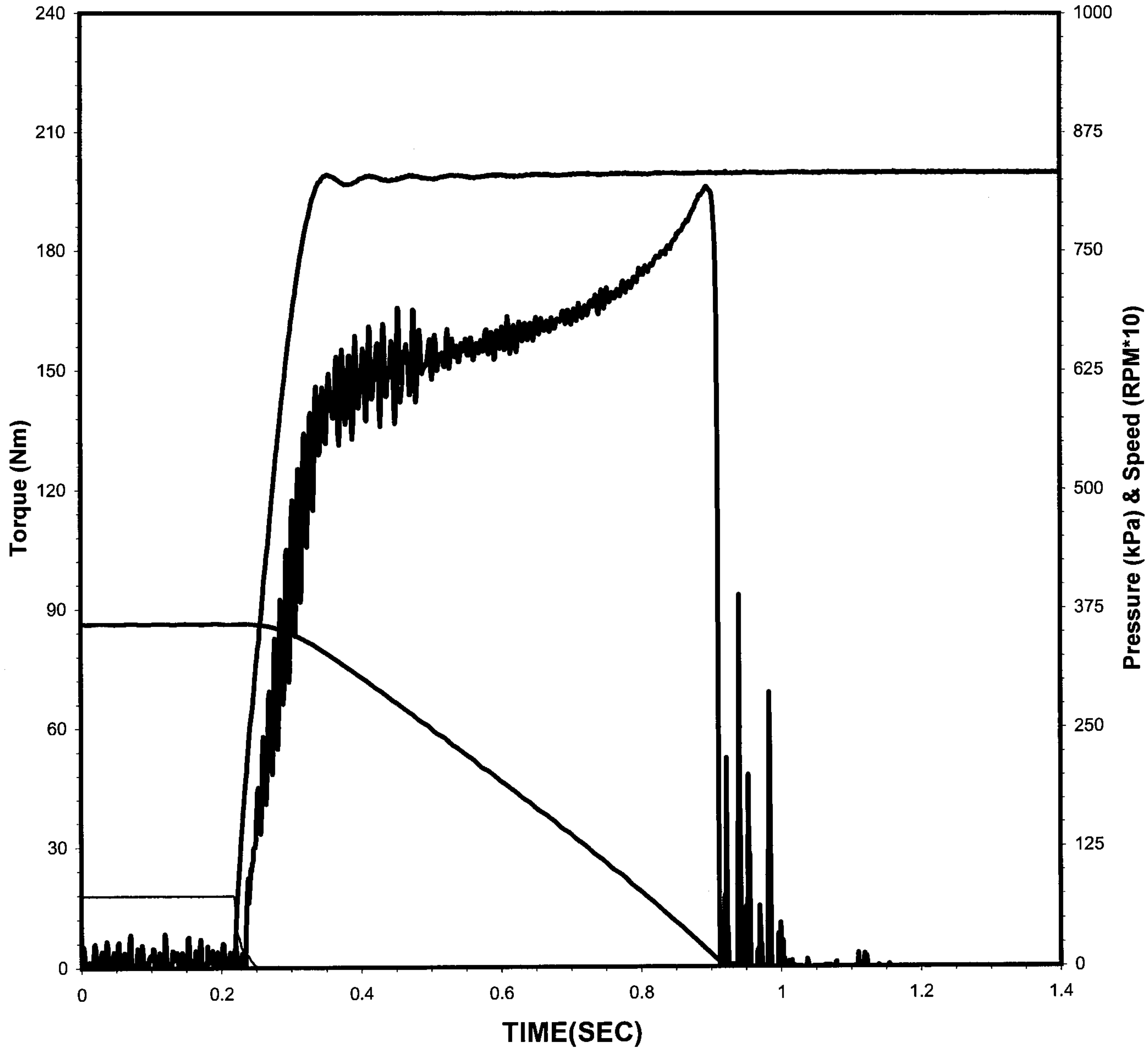
0.2 Sec Dyn:	**153 N*m**
Midpoint Dyn:	**159 N*m**
LwSpd Dynamic:	**187 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.106**
Midpoint Dyn:	**0.110**
LwSpd Dynamic:	**0.129**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	6:59:01
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	3499
Temperature:	113.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.693 Sec

Torque

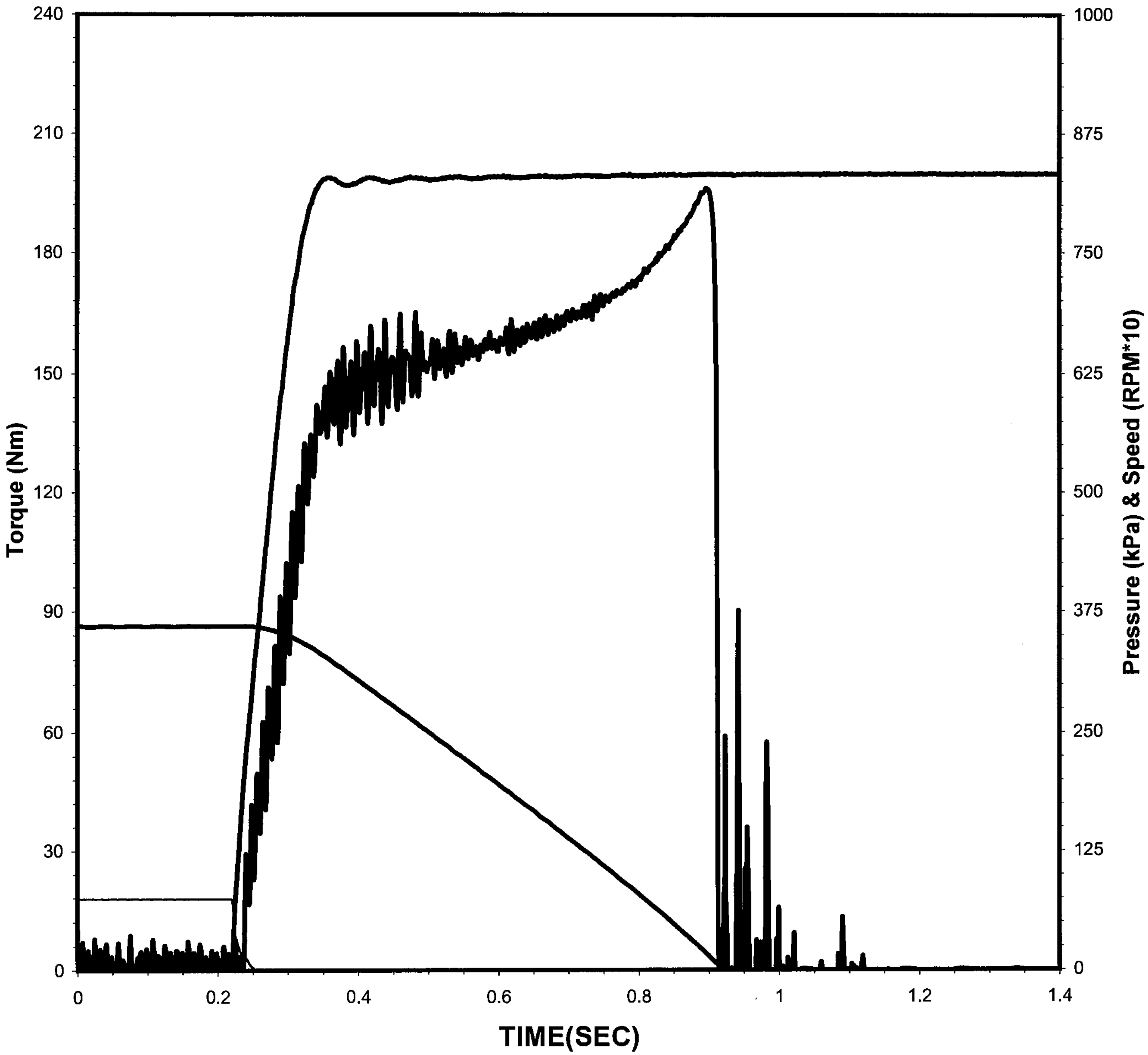
0.2 Sec Dyn:	150 N*m
Midpoint Dyn:	157 N*m
LwSpd Dynamic:	182 N*m

Coefficient of Friction

.2 Sec Dyn:	0.104
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/23/2010**
Time of Test:	**6:59:16**
Test Number:	**C4-9-1287**
Fluid Code:	**LO254054**
Cycle Number:	**3500**
Temperature:	**113.6 °C**
	(112.7 ± 3.0 °C)
Apply Pressure:	**829 kPa**
	827 ± 7 KPa)
Apply Rate:	**0.14 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.4 KJ**
	(18.71 ± 0.40 KJ)
Engage Time:	**0.694 Sec**

Torque

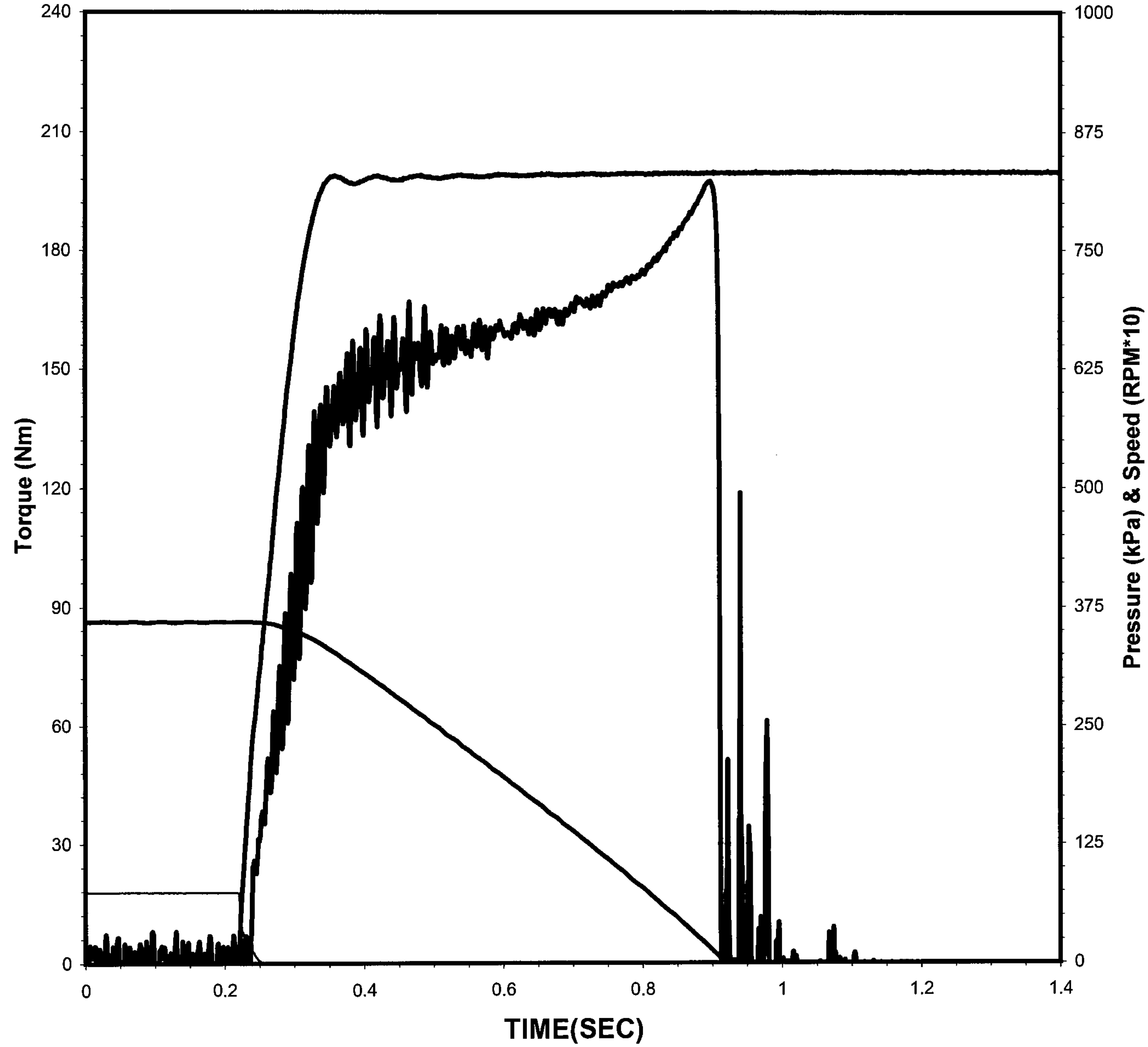
0.2 Sec Dyn:	**150 N*m**
Midpoint Dyn:	**157 N*m**
LwSpd Dynamic:	**183 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.104**
Midpoint Dyn:	**0.108**
LwSpd Dynamic:	**0.127**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	6:59:43
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	3501
Temperature:	109.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.692 Sec

Torque

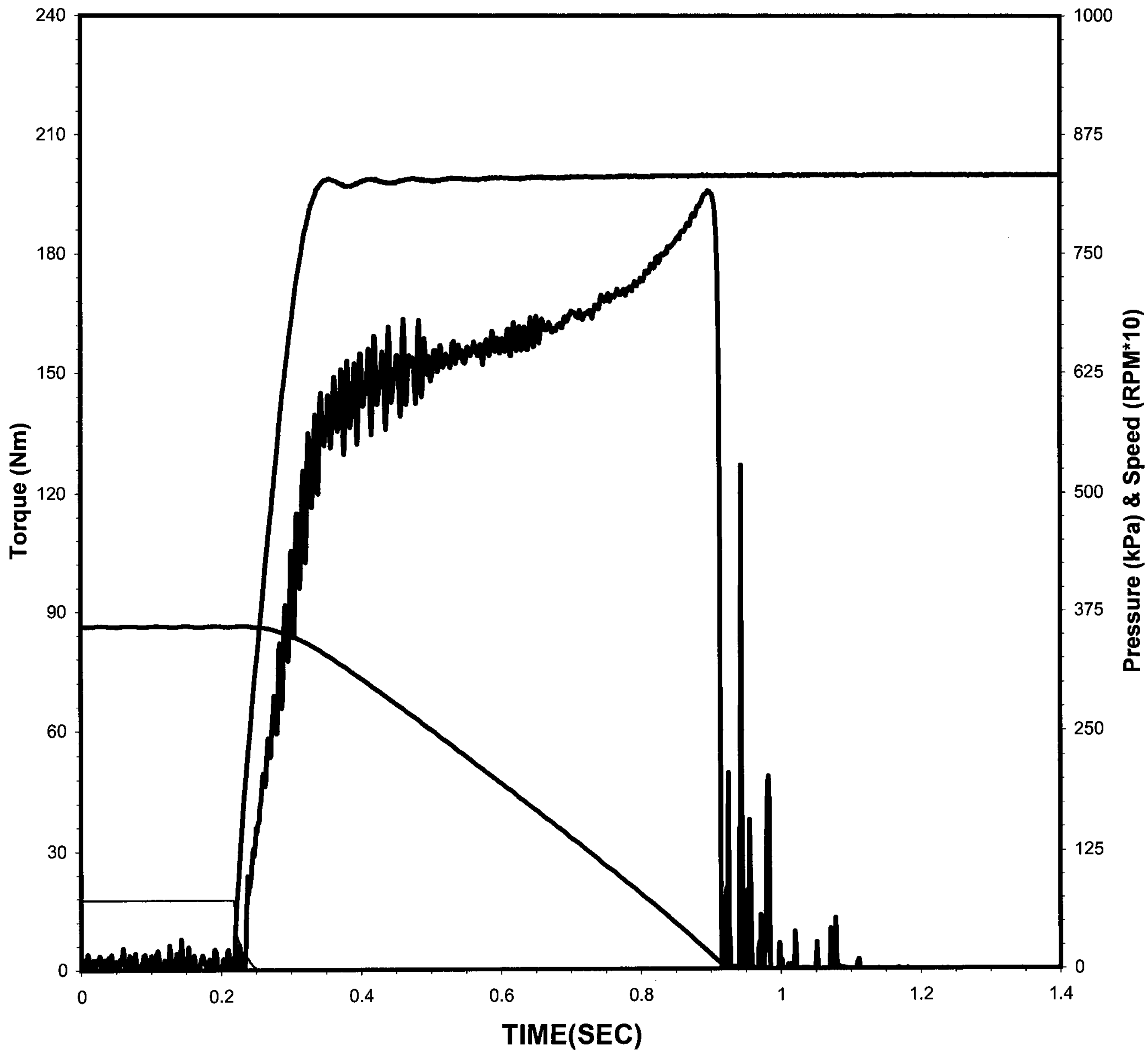
0.2 Sec Dyn:	151 N*m
Midpoint Dyn:	158 N*m
LwSpd Dynamic:	185 N*m

Coefficient of Friction

.2 Sec Dyn:	0.104
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	9:04:13
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	3999
Temperature:	113.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.696 Sec

Torque

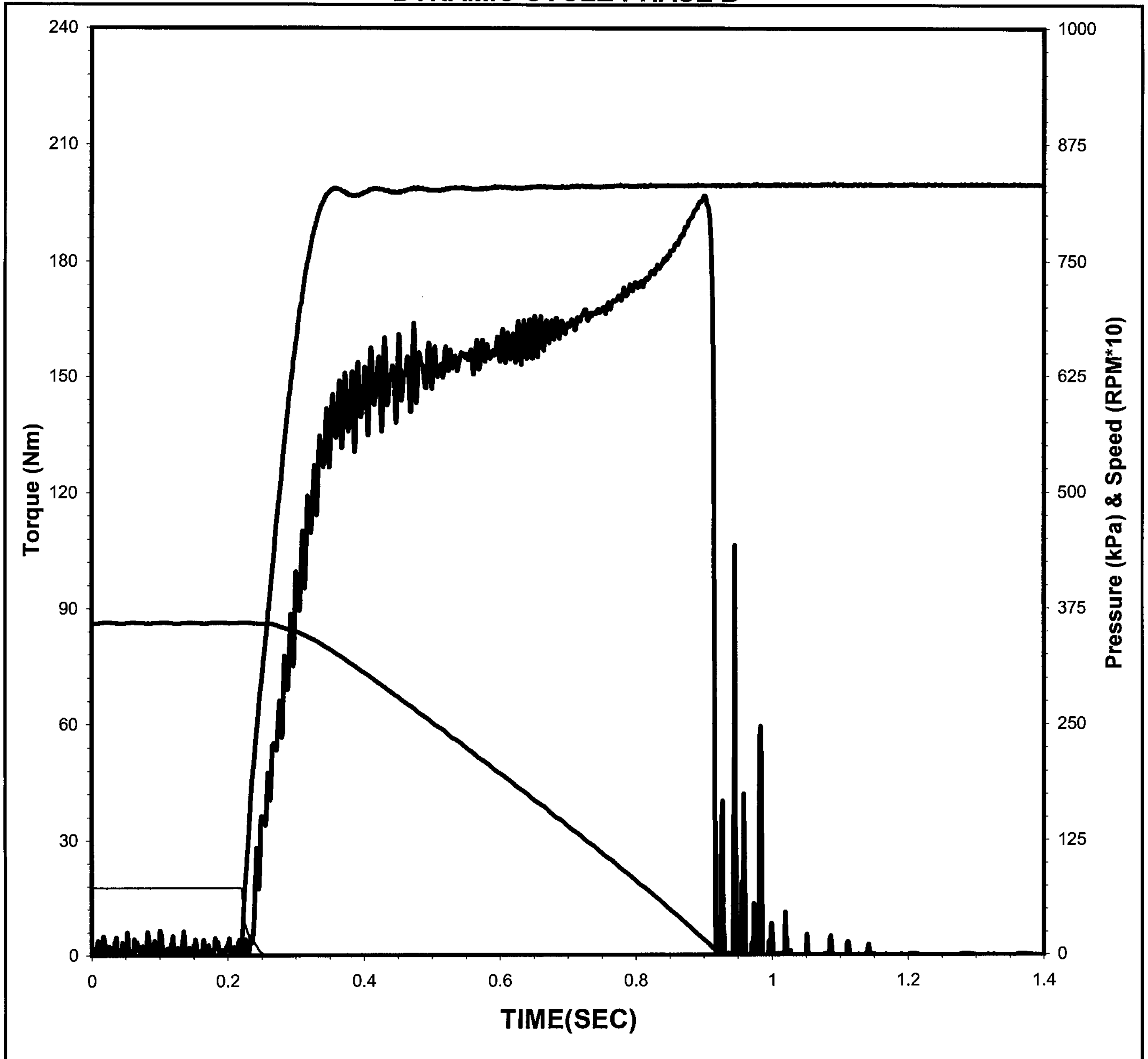
0.2 Sec Dyn:	148 N*m
Midpoint Dyn:	156 N*m
LwSpd Dynamic:	181 N*m

Coefficient of Friction

.2 Sec Dyn:	0.102
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/23/2010**
Time of Test:	**9:04:28**
Test Number:	**C4-9-1287**
Fluid Code:	**LO254054**
Cycle Number:	**4000**
Temperature:	**114.0 °C**
	(112.7 ± 3.0 °C)
Apply Pressure:	**829 kPa**
	827 ± 7 KPa)
Apply Rate:	**0.14 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.4 KJ**
	(18.71 ± 0.40 KJ)
Engage Time:	**0.697 Sec**

Torque

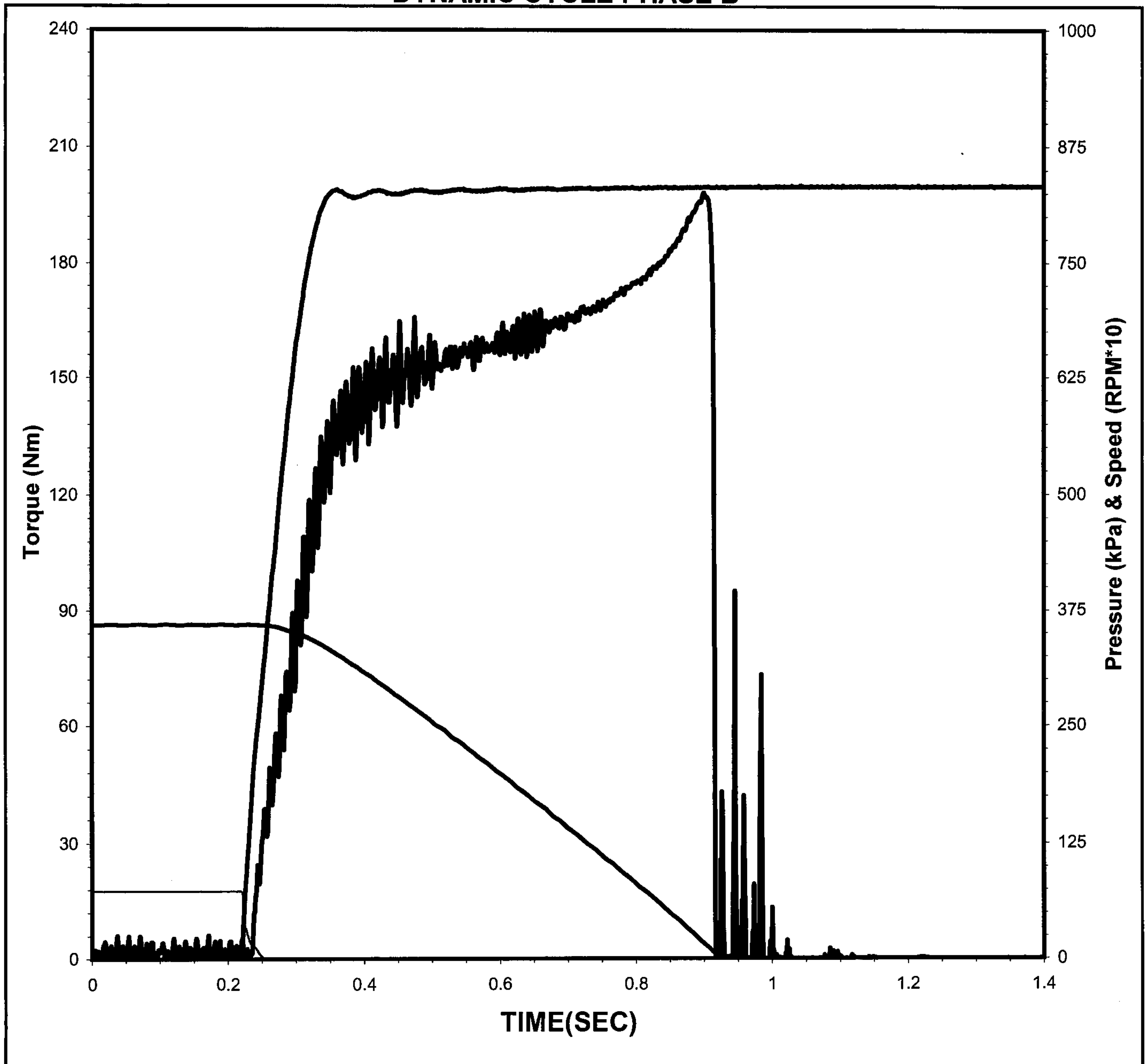
0.2 Sec Dyn:	**147 N*m**
Midpoint Dyn:	**156 N*m**
LwSpd Dynamic:	**185 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.102**
Midpoint Dyn:	**0.108**
LwSpd Dynamic:	**0.128**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	9:04:54
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	4001
Temperature:	108.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	829 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.696 Sec

Torque

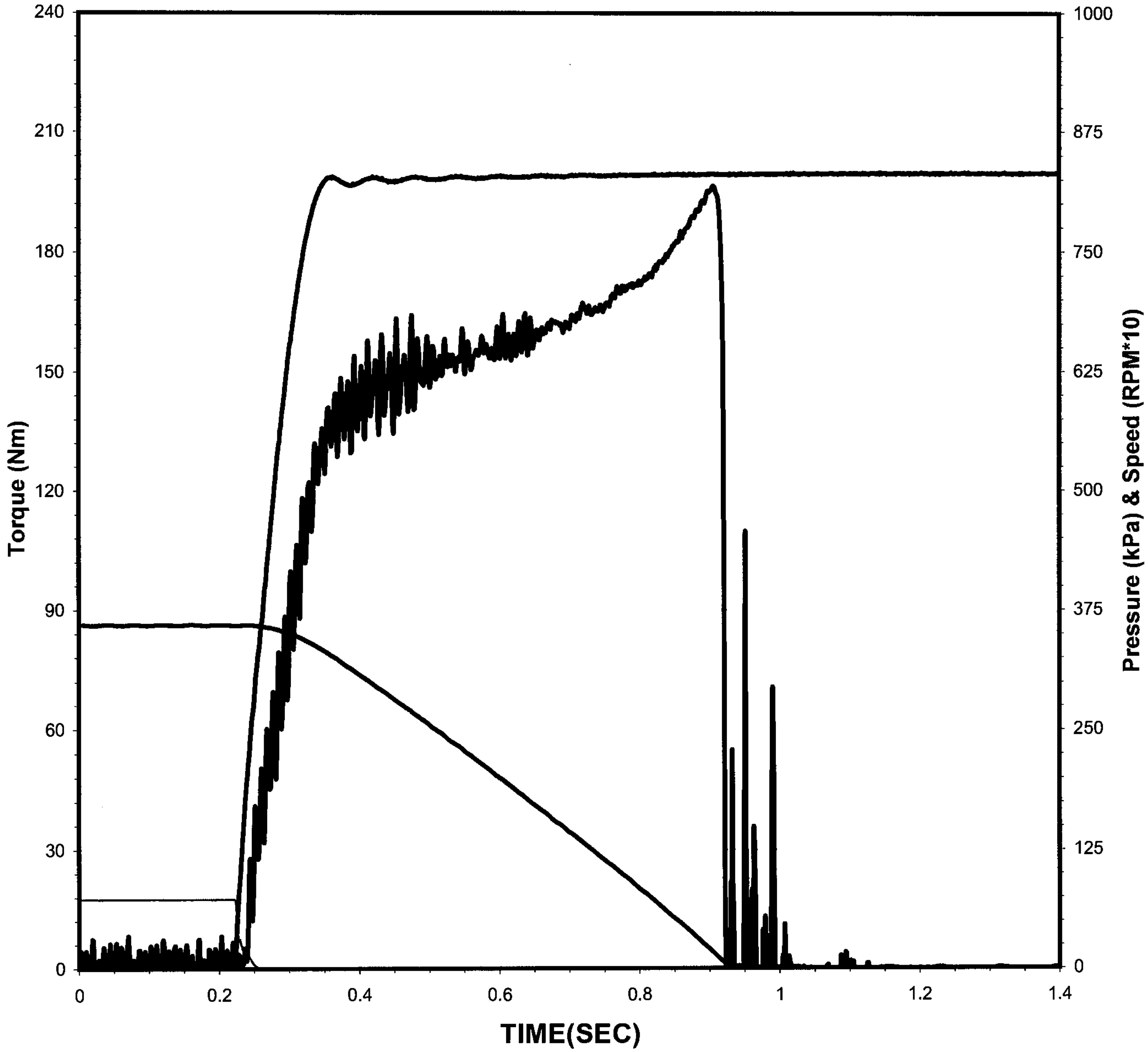
0.2 Sec Dyn:	147 N*m
Midpoint Dyn:	158 N*m
LwSpd Dynamic:	183 N*m

Coefficient of Friction

.2 Sec Dyn:	0.102
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	11:09:24
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	4499
Temperature:	113.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	828 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.7 Sec

Torque

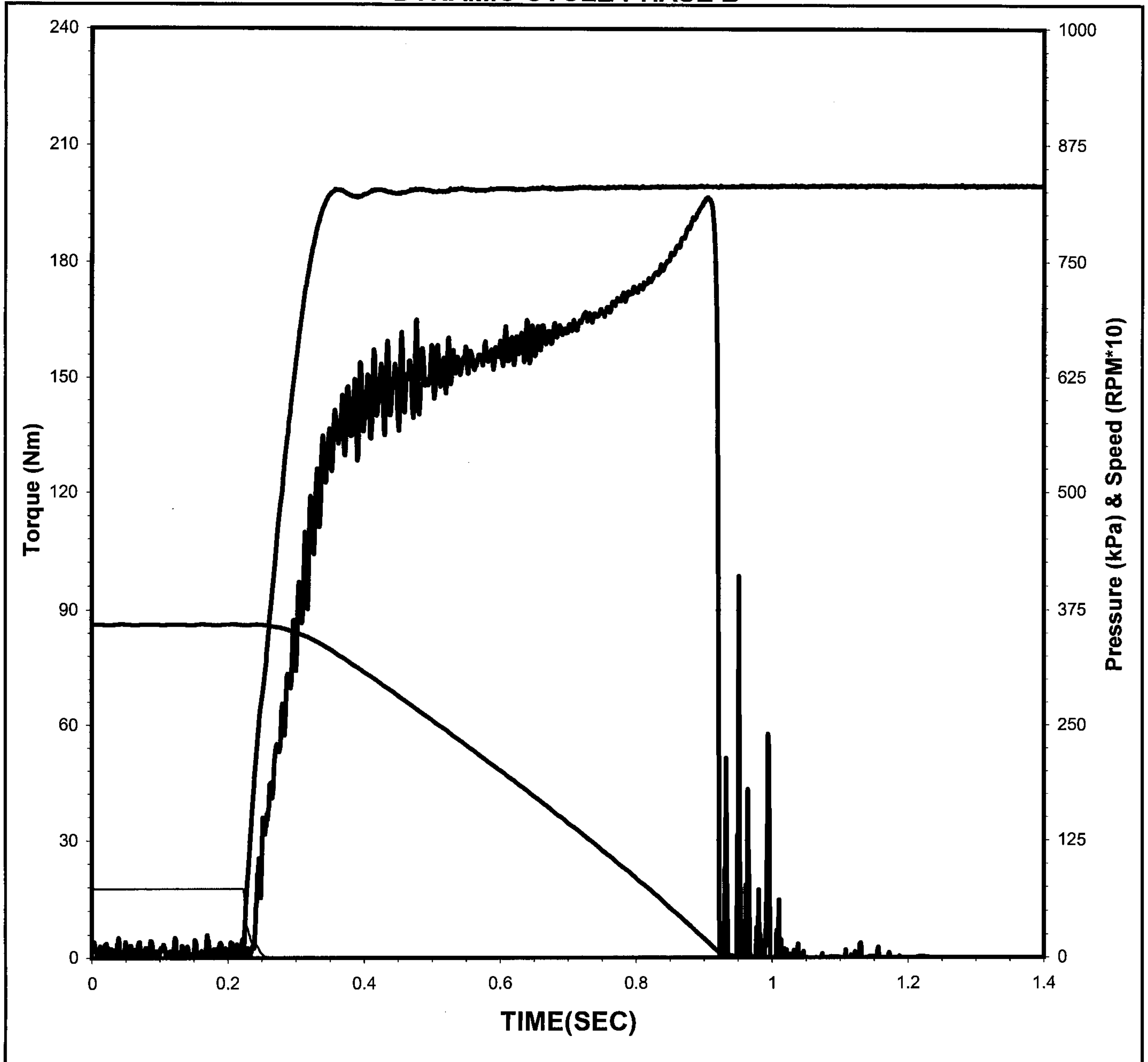
0.2 Sec Dyn:	147 N*m
Midpoint Dyn:	156 N*m
LwSpd Dynamic:	182 N*m

Coefficient of Friction

.2 Sec Dyn:	0.101
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/23/2010

Time of Test: 11:09:40

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 4500

Temperature: 113.4 °C
(112.7 ± 3.0 °C)

Apply Pressure: 828 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.3 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.7 Sec

Torque

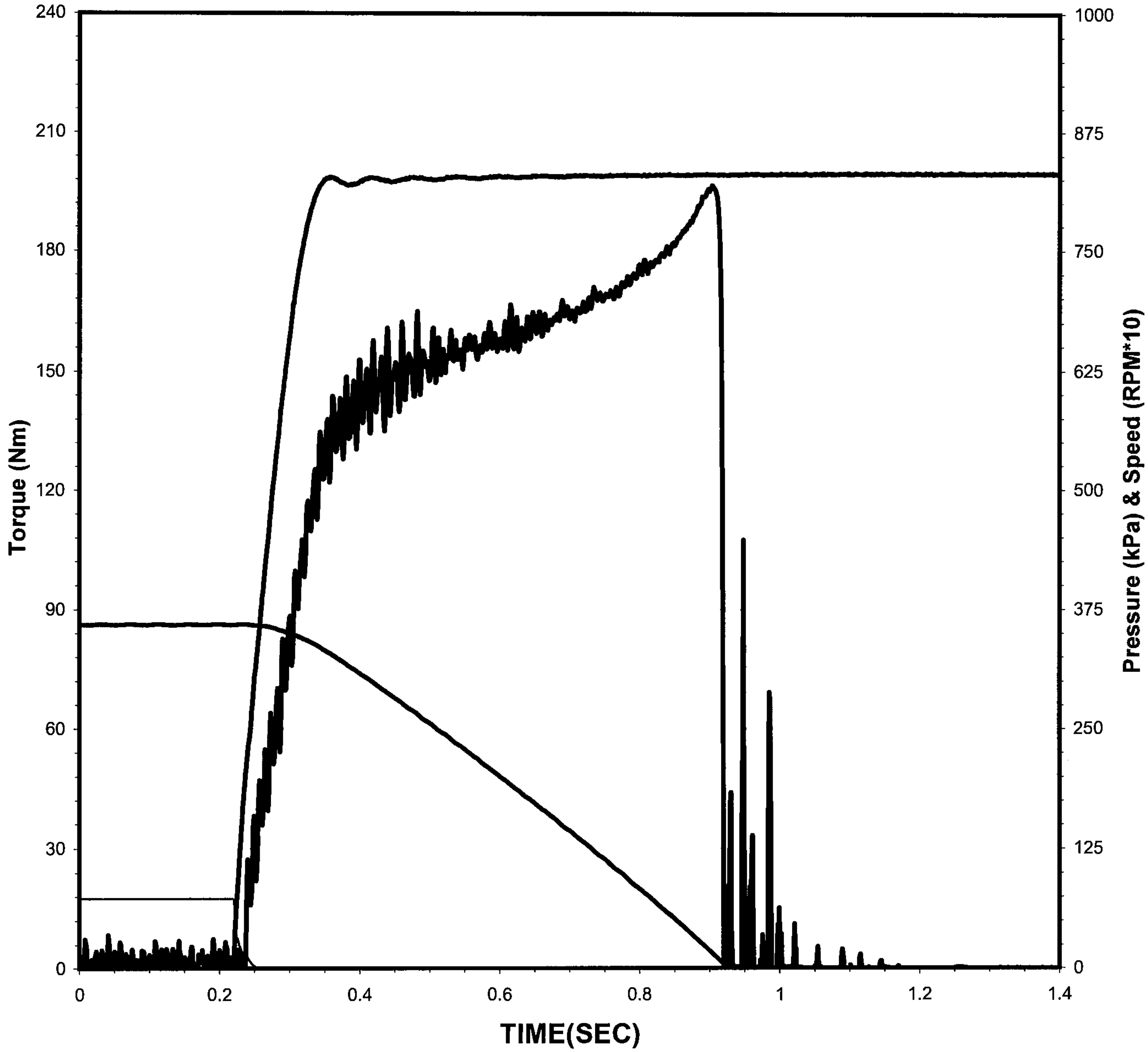
0.2 Sec Dyn:	145 N*m
Midpoint Dyn:	156 N*m
LwSpd Dynamic:	183 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/23/2010

Time of Test: 11:10:06

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 4501

Temperature: 108.8 °C
(112.7 ± 3.0 °C)

Apply Pressure: 828 kPa
827 ± 7 KPa)

Apply Rate: 0.14 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.7 Sec

Torque

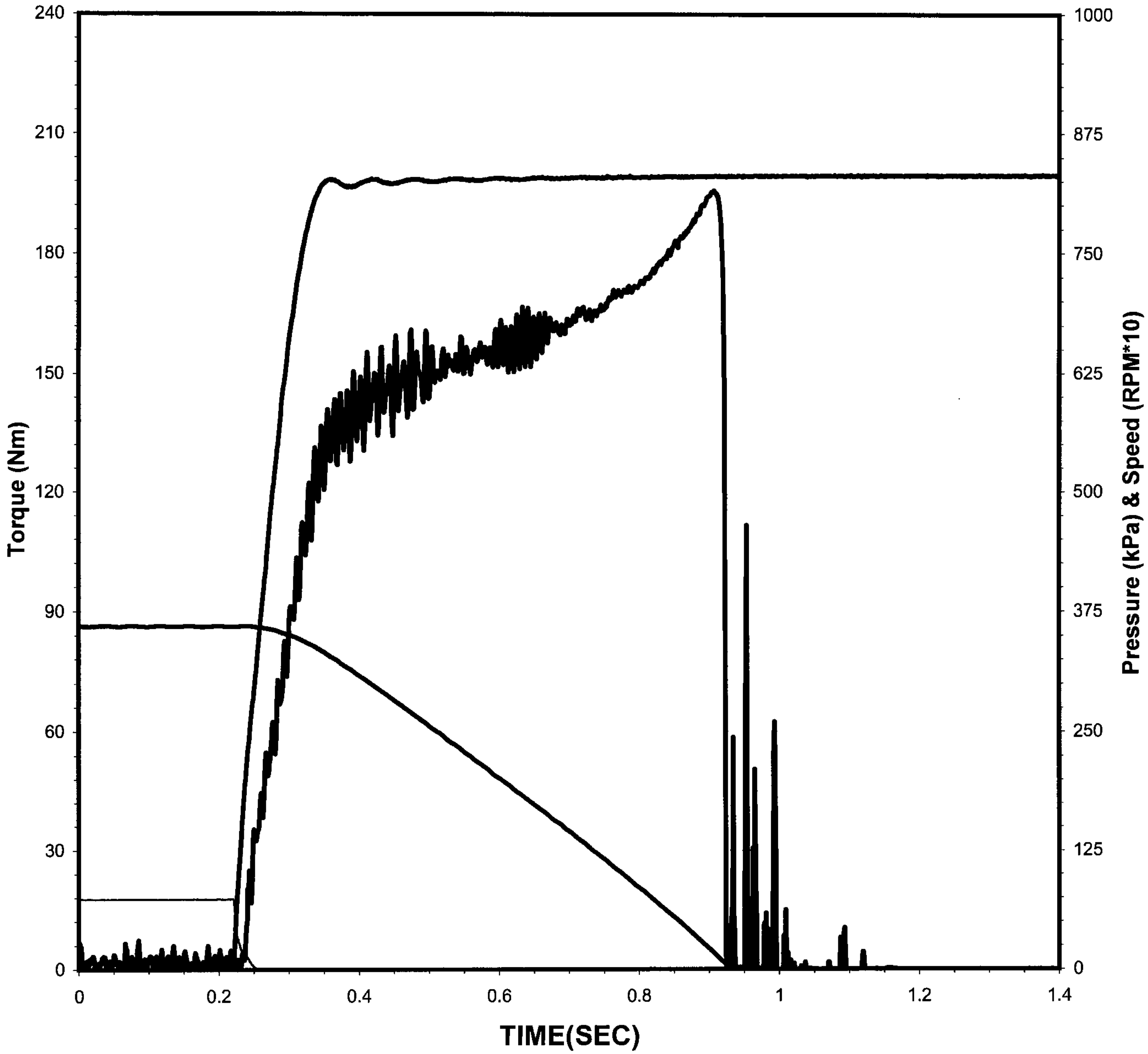
0.2 Sec Dyn: 146 N*m
Midpoint Dyn: 157 N*m
LwSpd Dynamic: 183 N*m

Coefficient of Friction

.2 Sec Dyn: 0.101
Midpoint Dyn: 0.109
LwSpd Dynamic: 0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/23/2010

Time of Test: 13:14:36

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 4999

Temperature: 113.6 °C
(112.7 ± 3.0 °C)

Apply Pressure: 827 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.703 Sec

Torque

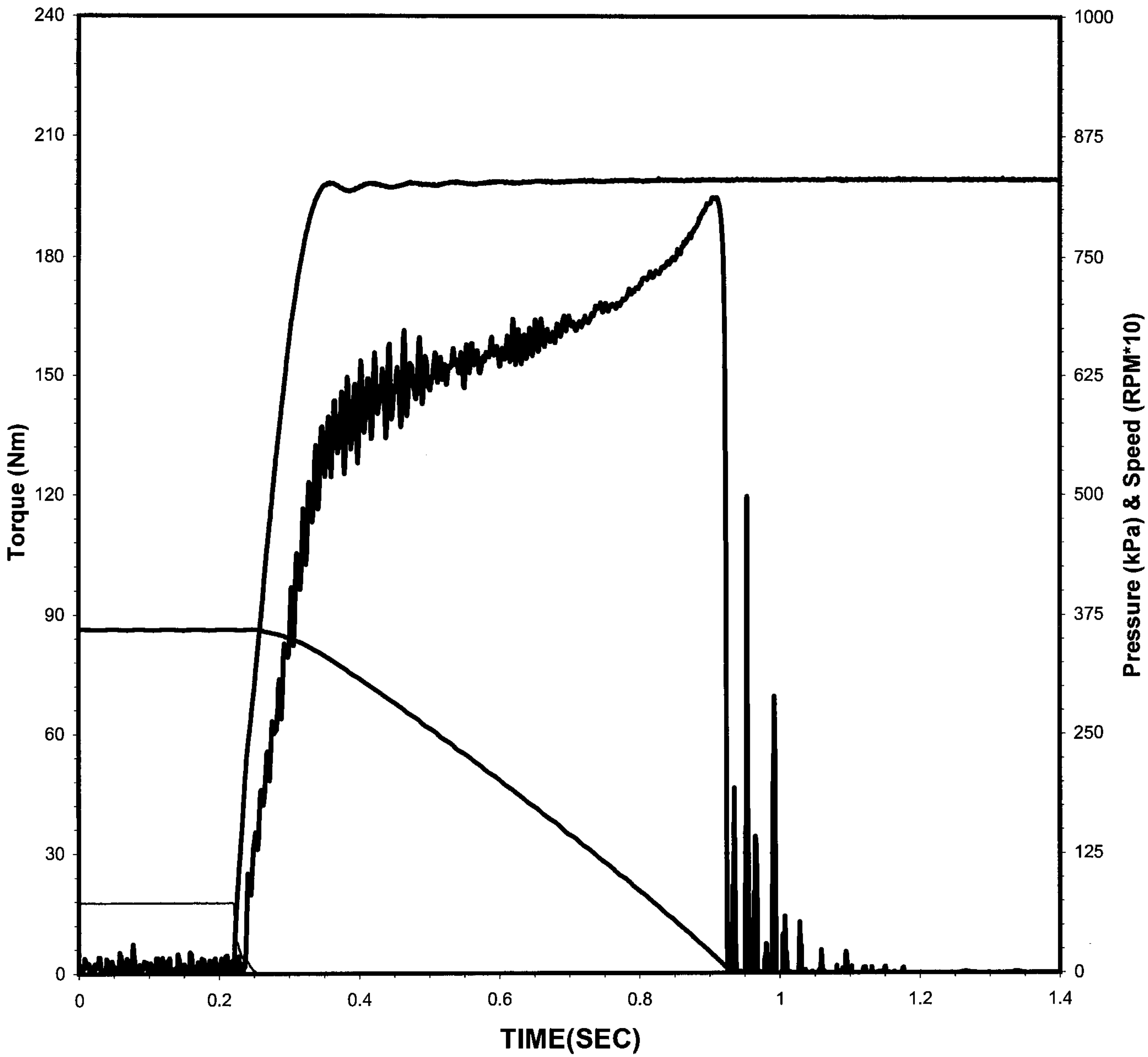
0.2 Sec Dyn:	144 N*m
Midpoint Dyn:	155 N*m
LwSpd Dynamic:	181 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	13:14:51
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	5000
Temperature:	113.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	828 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.704 Sec

Torque

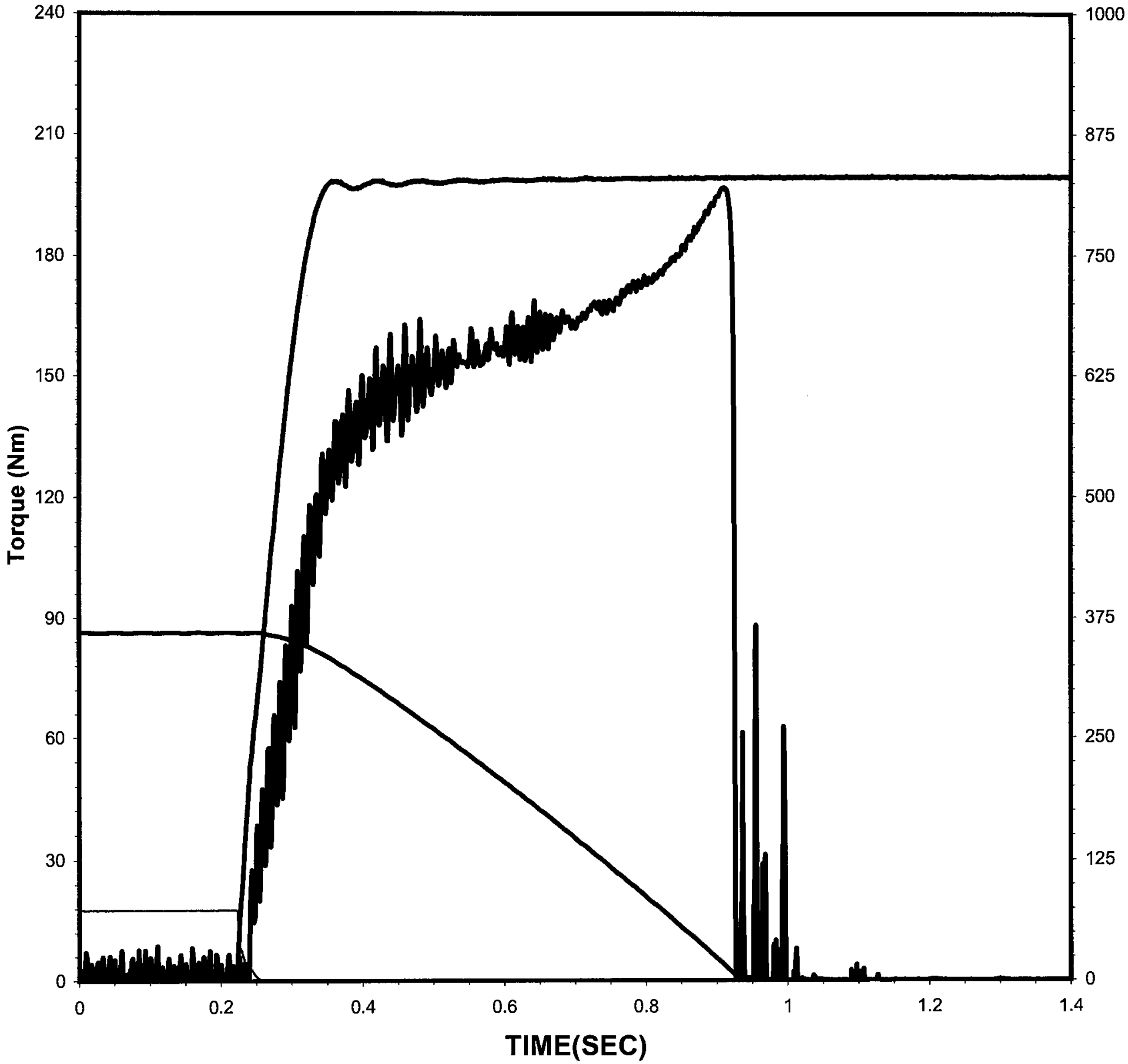
0.2 Sec Dyn:	145 N*m
Midpoint Dyn:	155 N*m
LwSpd Dynamic:	180 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.124

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	13:15:18
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	5001
Temperature:	109.6 °C (112.7 ± 3.0 °C)
Apply Pressure:	828 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.704 Sec

Torque

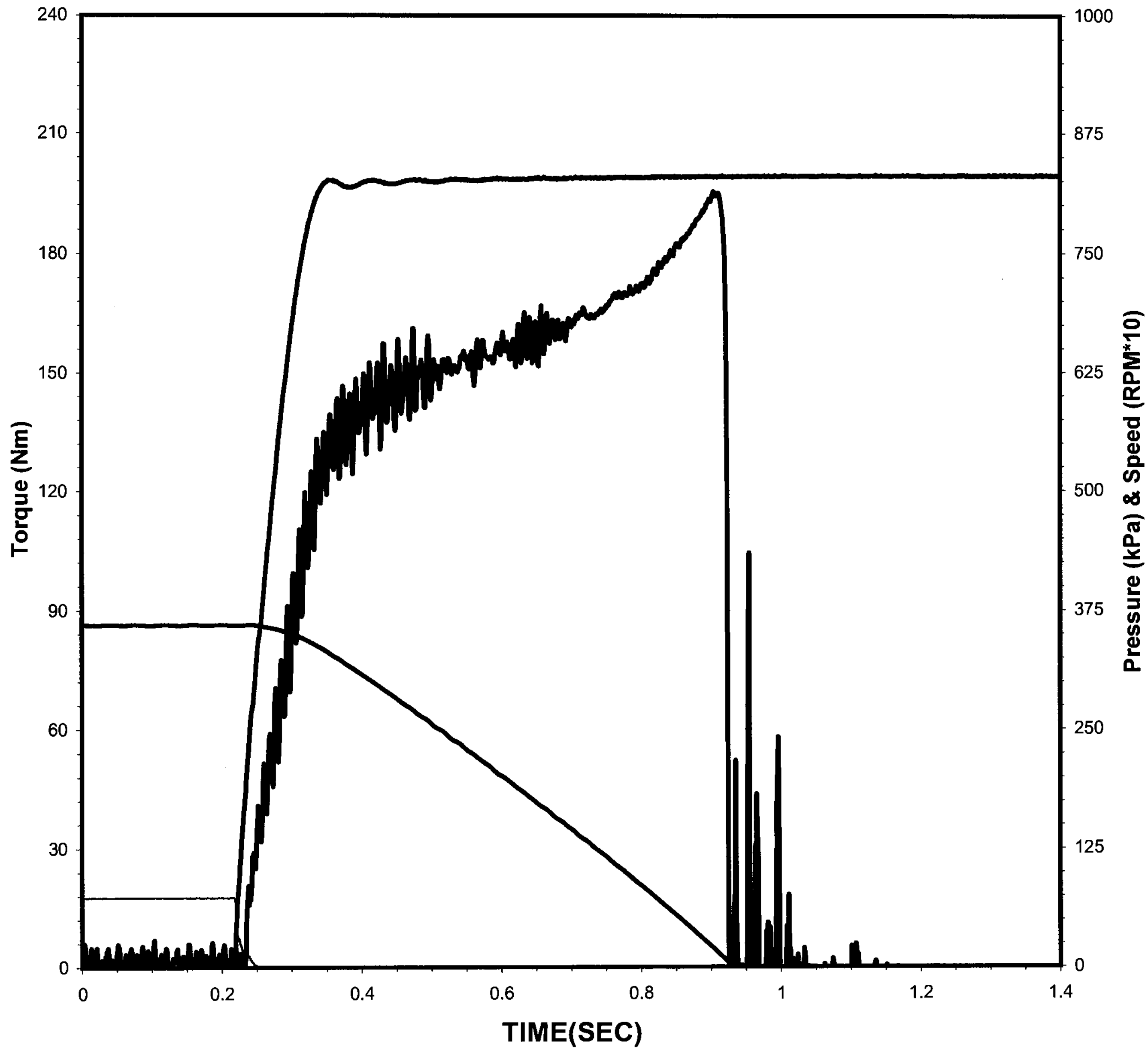
0.2 Sec Dyn:	147 N*m
Midpoint Dyn:	157 N*m
LwSpd Dynamic:	185 N*m

Coefficient of Friction

.2 Sec Dyn:	0.102
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/23/2010**
Time of Test:	**15:19:33**
Test Number:	**C4-9-1287**
Fluid Code:	**LO254054**
Cycle Number:	**5498**
Temperature:	**113.8 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**827 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.706 Sec**

Torque

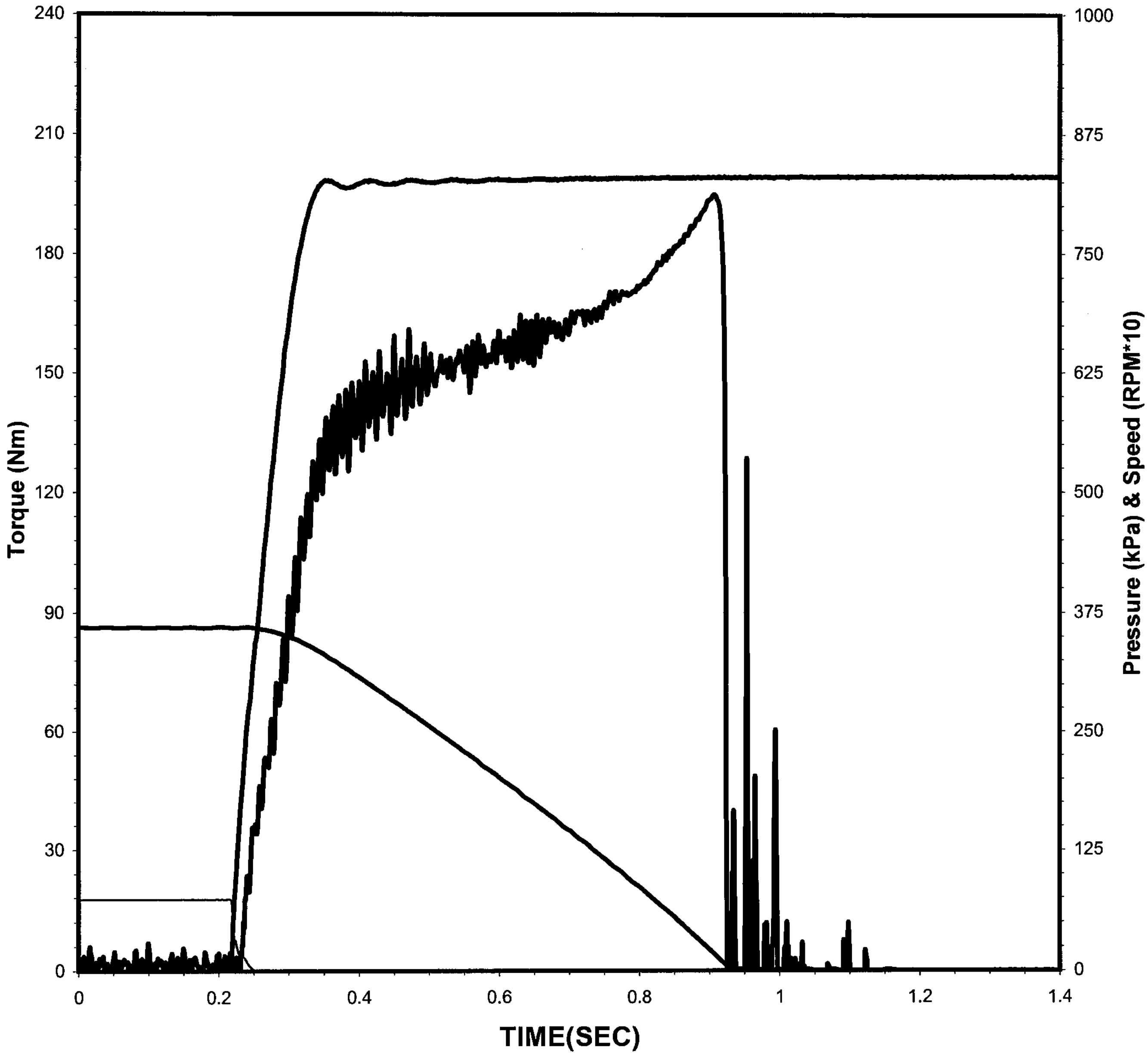
0.2 Sec Dyn:	**143 N*m**
Midpoint Dyn:	**154 N*m**
LwSpd Dynamic:	**180 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.099**
Midpoint Dyn:	**0.107**
LwSpd Dynamic:	**0.125**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/23/2010
Time of Test:	15:19:48
Test Number:	C4-9-1287
Fluid Code:	LO254054
Cycle Number:	5499
Temperature:	113.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	827 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.707 Sec

Torque

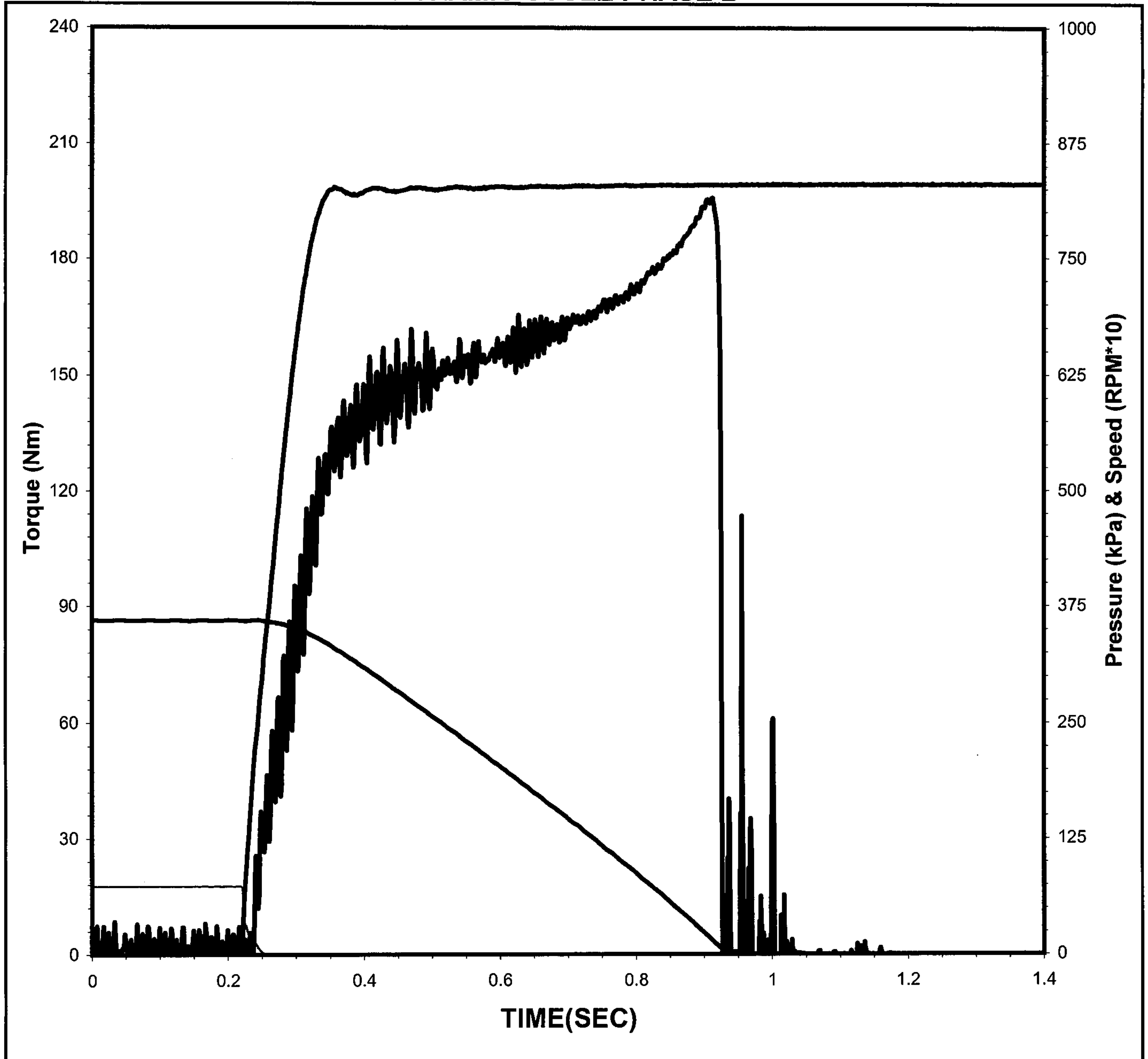
0.2 Sec Dyn:	143 N*m
Midpoint Dyn:	154 N*m
LwSpd Dynamic:	178 N*m

Coefficient of Friction

.2 Sec Dyn:	0.099
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.123

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/23/2010

Time of Test: 15:20:03

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 5500

Temperature: 113.8 °C
(112.7 ± 3.0 °C)
Apply Pressure: 827 kPa
827 ± 7 KPa)
Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)
Energy: 18.4 KJ
(18.71 ± 0.40 KJ)
Engage Time: 0.706 Sec

Torque

0.2 Sec Dyn: 146 N*m
Midpoint Dyn: 155 N*m
LwSpd Dynamic: 184 N*m

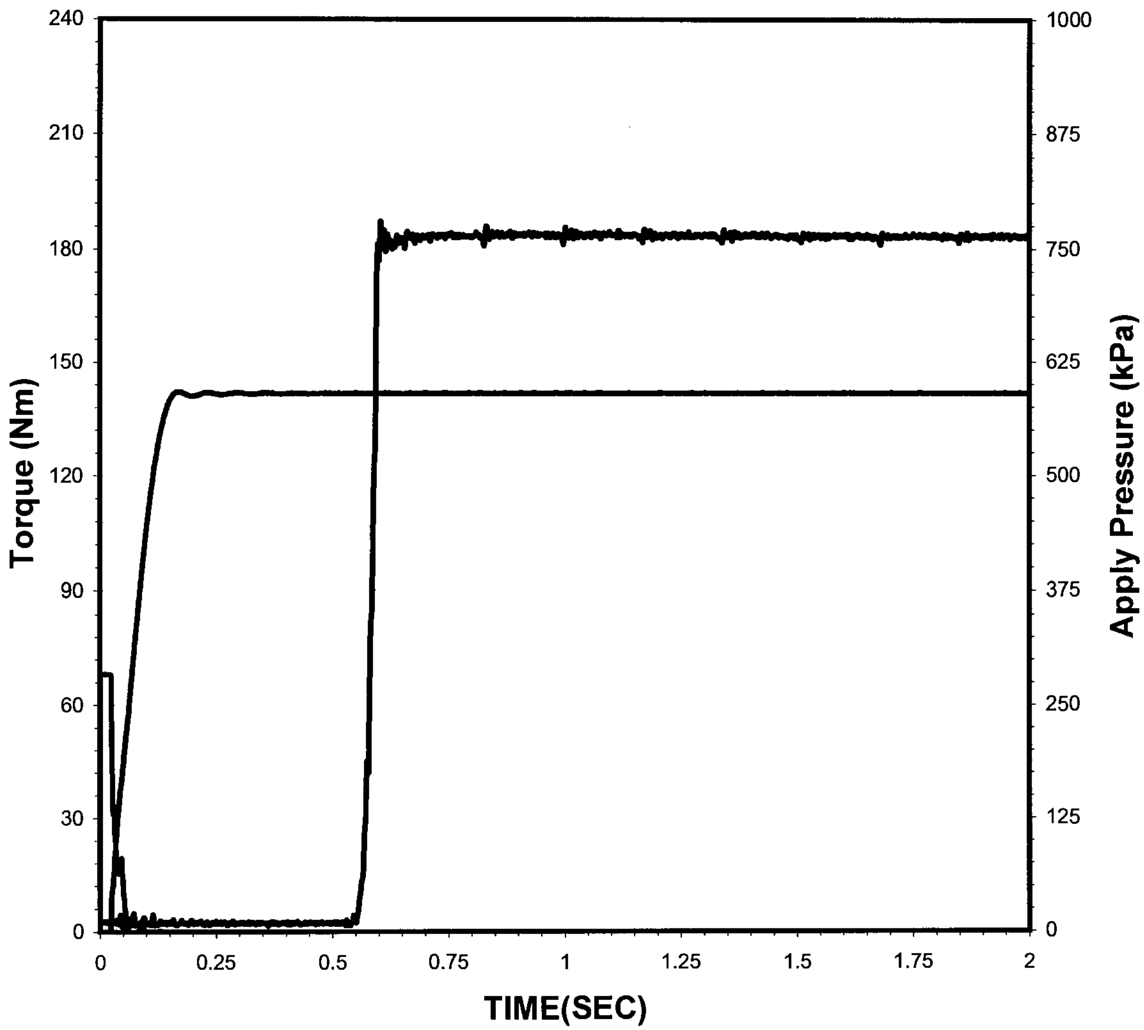
Coefficient of Friction

.2 Sec Dyn: 0.101
Midpoint Dyn: 0.107
LwSpd Dynamic: 0.127

STATIC TRACES

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 16:02:32

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 10

PHASE A

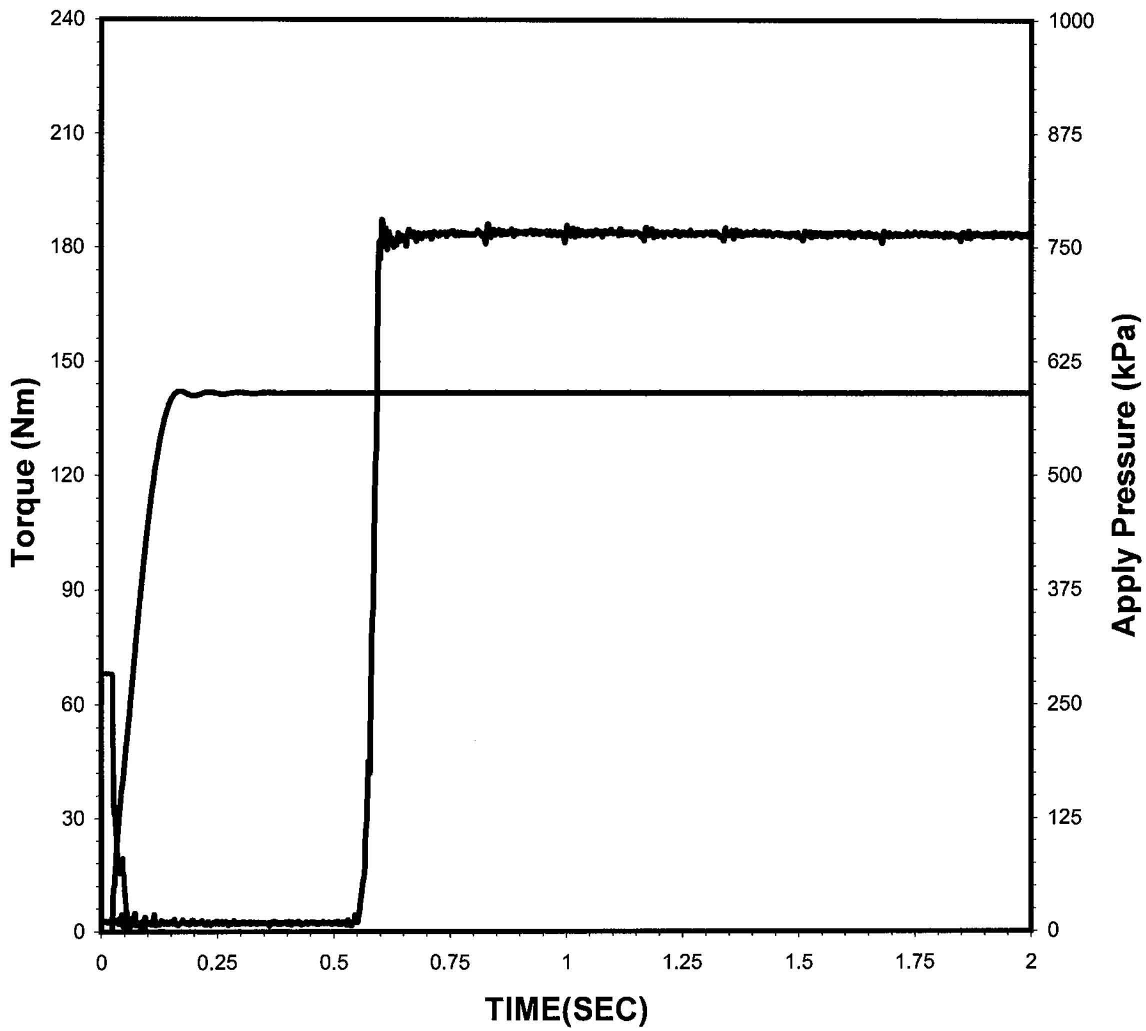
Apply Pressure:
At .25 Second: 348 kPa

Torque
Static Peak: 117 Nm
.25 Second: 87 Nm

Coefficient of Friction
Static Peak: 0.194
.25 Second: 0.145

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 18:05:14

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 500

PHASE A

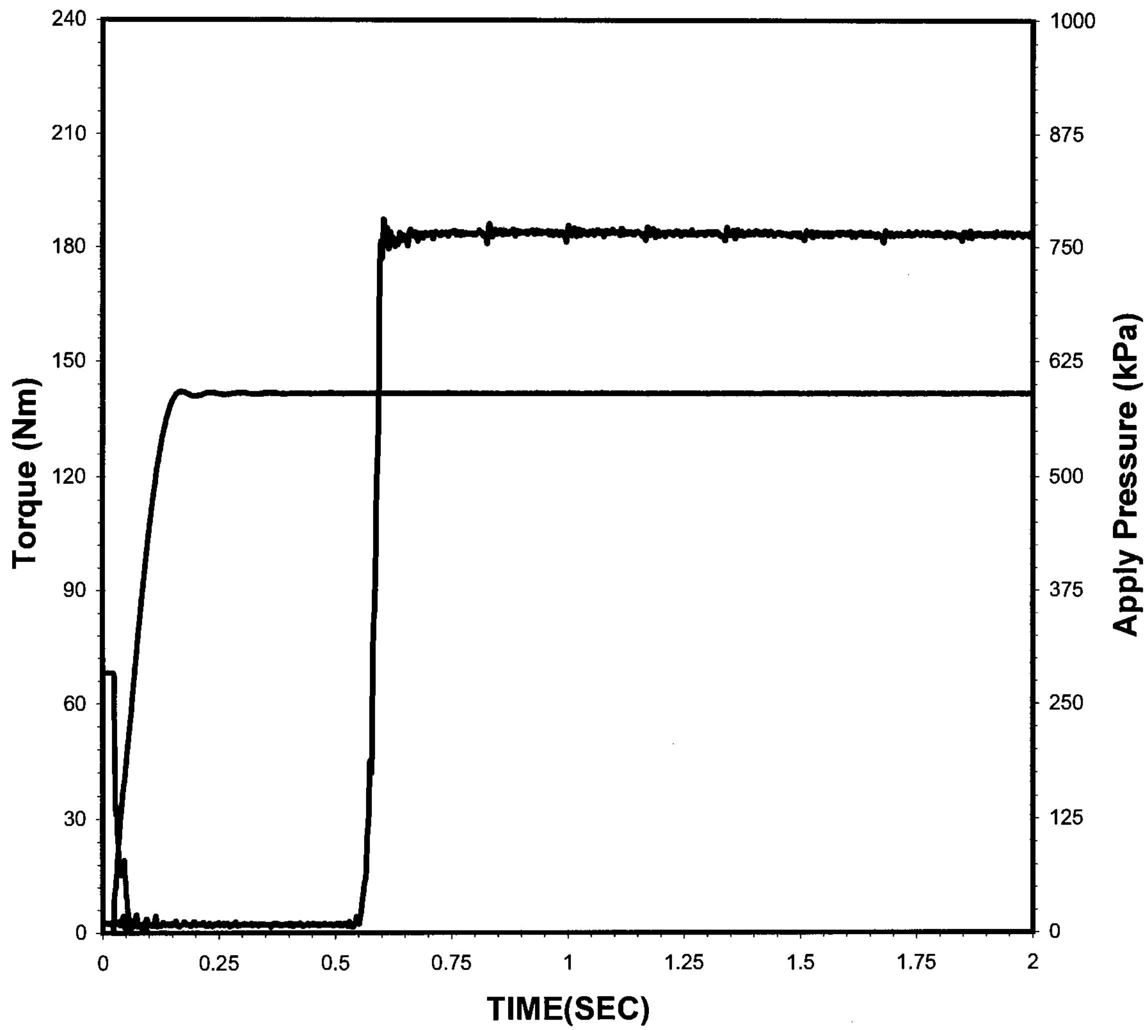
Apply Pressure:
At .25 Second: 348 kPa

Torque
Static Peak: 103 Nm
.25 Second: 87 Nm

Coefficient of Friction
Static Peak: 0.172
.25 Second: 0.145

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 20:10:26

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 1000

PHASE A

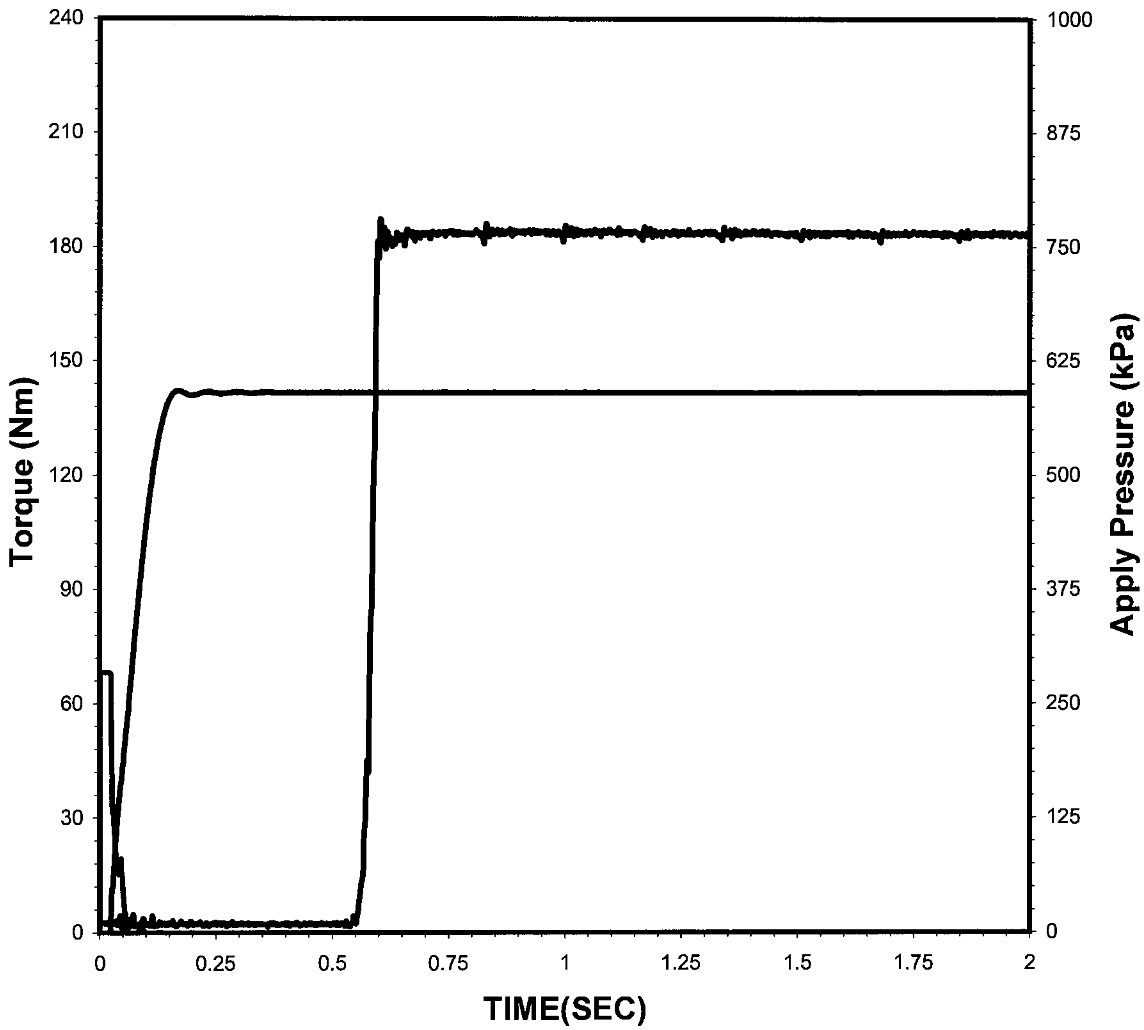
Apply Pressure:
At .25 Second: 348 kPa

Torque
Static Peak: 102 Nm
.25 Second: 86 Nm

Coefficient of Friction
Static Peak: 0.169
.25 Second: 0.143

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 22:38:40

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 1500

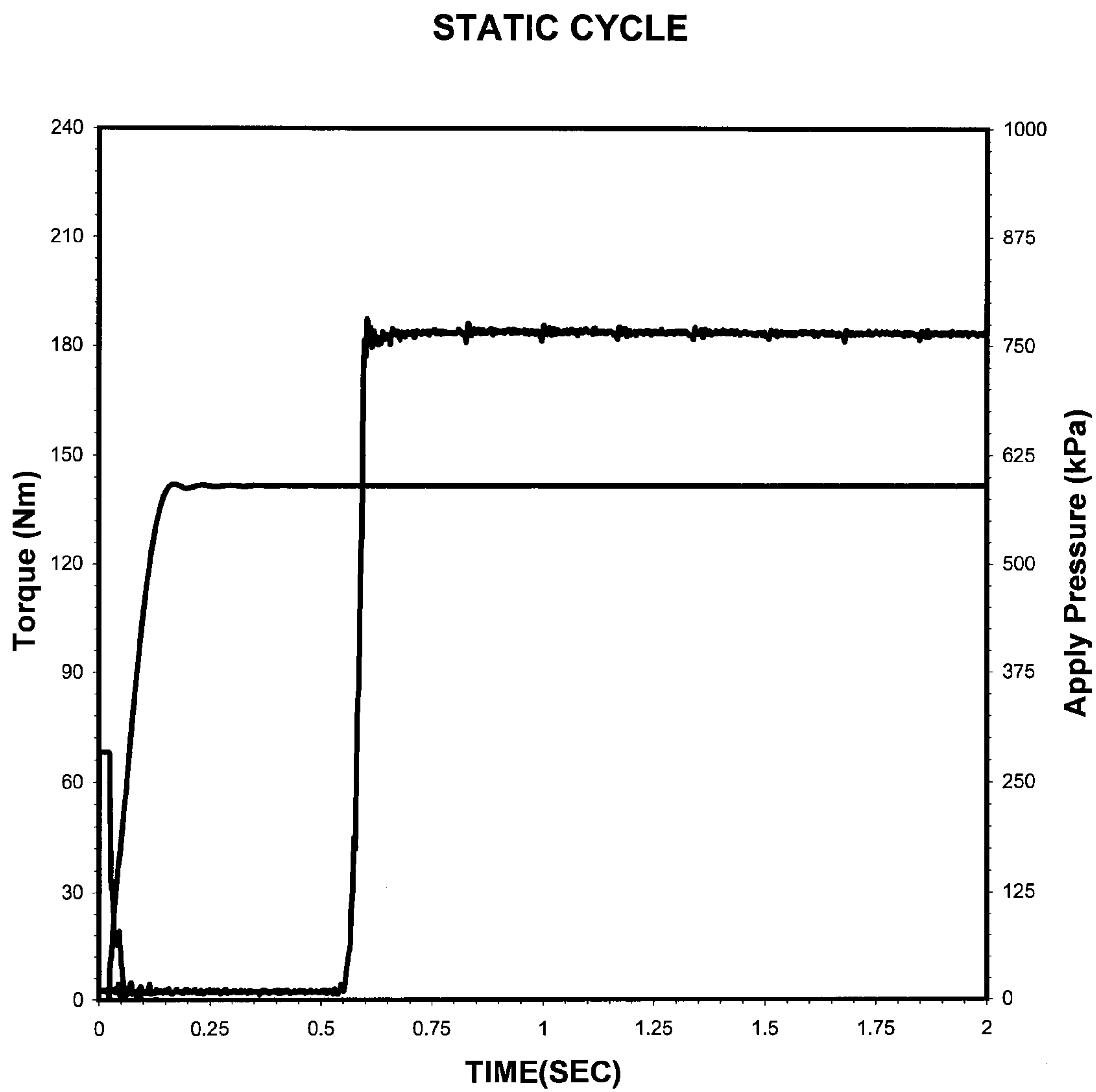
PHASE B

Apply Pressure:
At .25 Second: 828 kPa

Torque
Static Peak: 201 Nm
.25 Second: 192 Nm

Coefficient of Friction
Static Peak: 0.139
.25 Second: 0.133

ALLISON C-4 GRAPHITE DATA



Date of Test: 7/23/2010

Time of Test: 0:43:52

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 2000

PHASE B

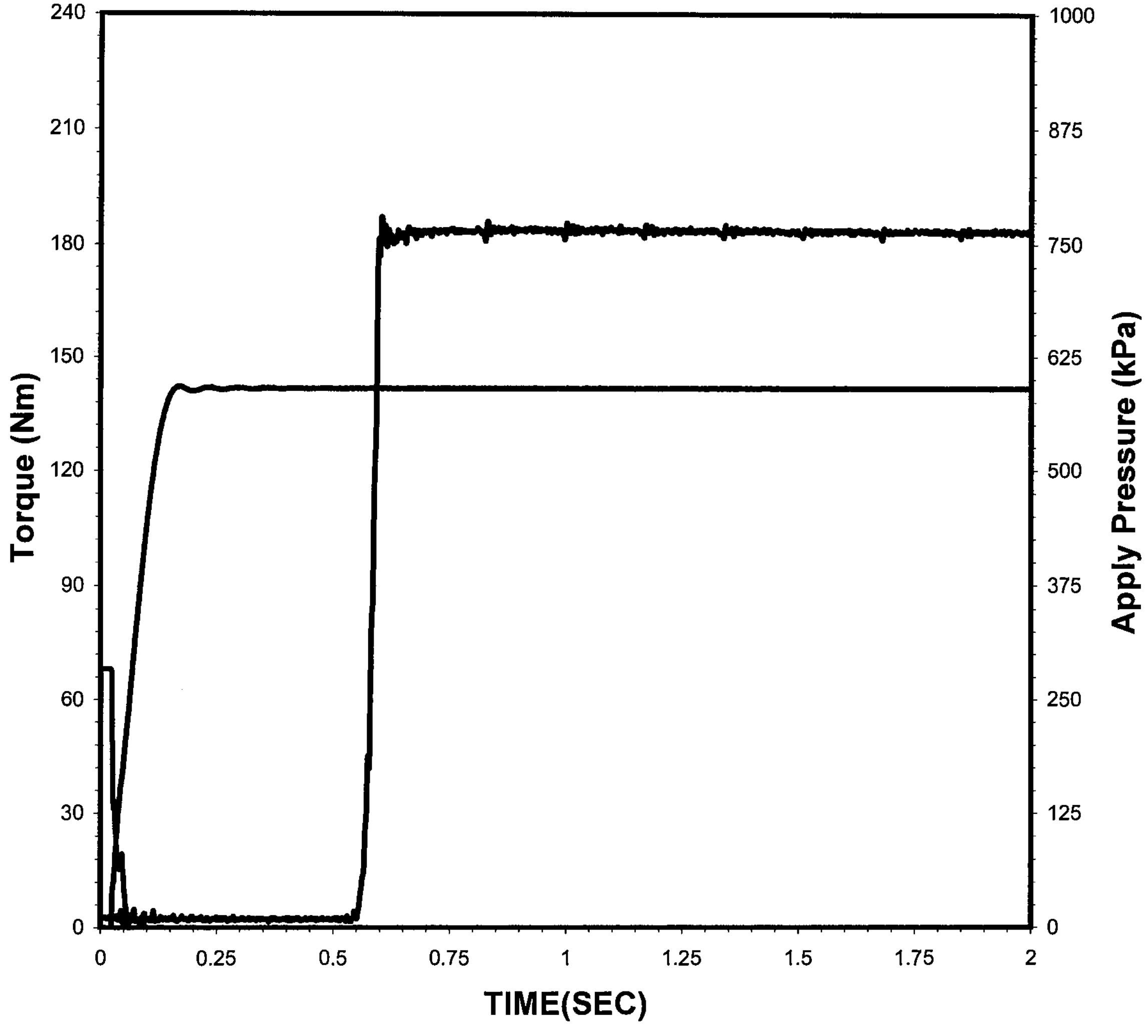
Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 201 Nm
.25 Second: 192 Nm

Coefficient of Friction
Static Peak: 0.139
.25 Second: 0.133

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 2:49:04

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 2500

PHASE B

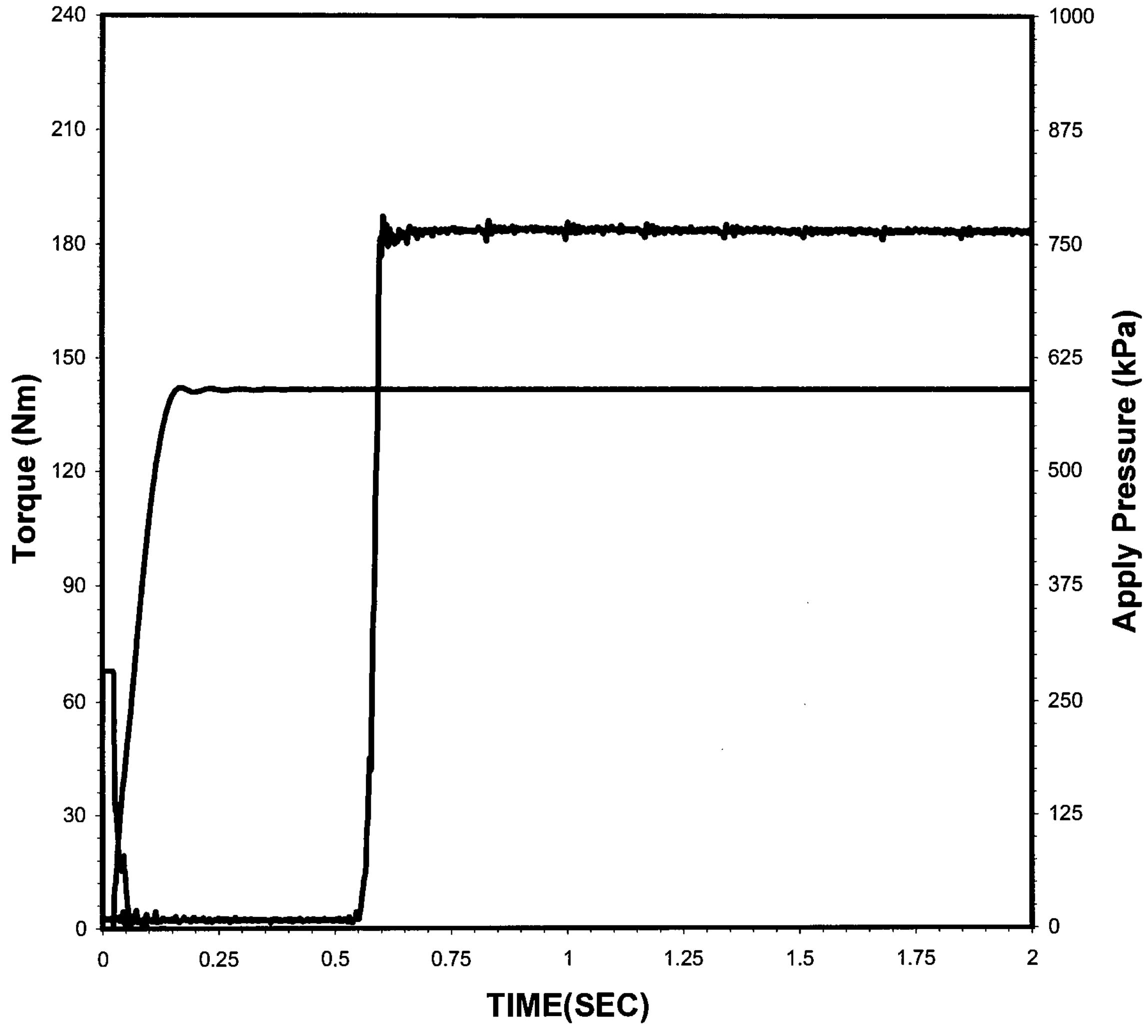
Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 205 Nm
.25 Second: 192 Nm

Coefficient of Friction
Static Peak: 0.141
.25 Second: 0.133

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 4:54:16

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 3000

PHASE B

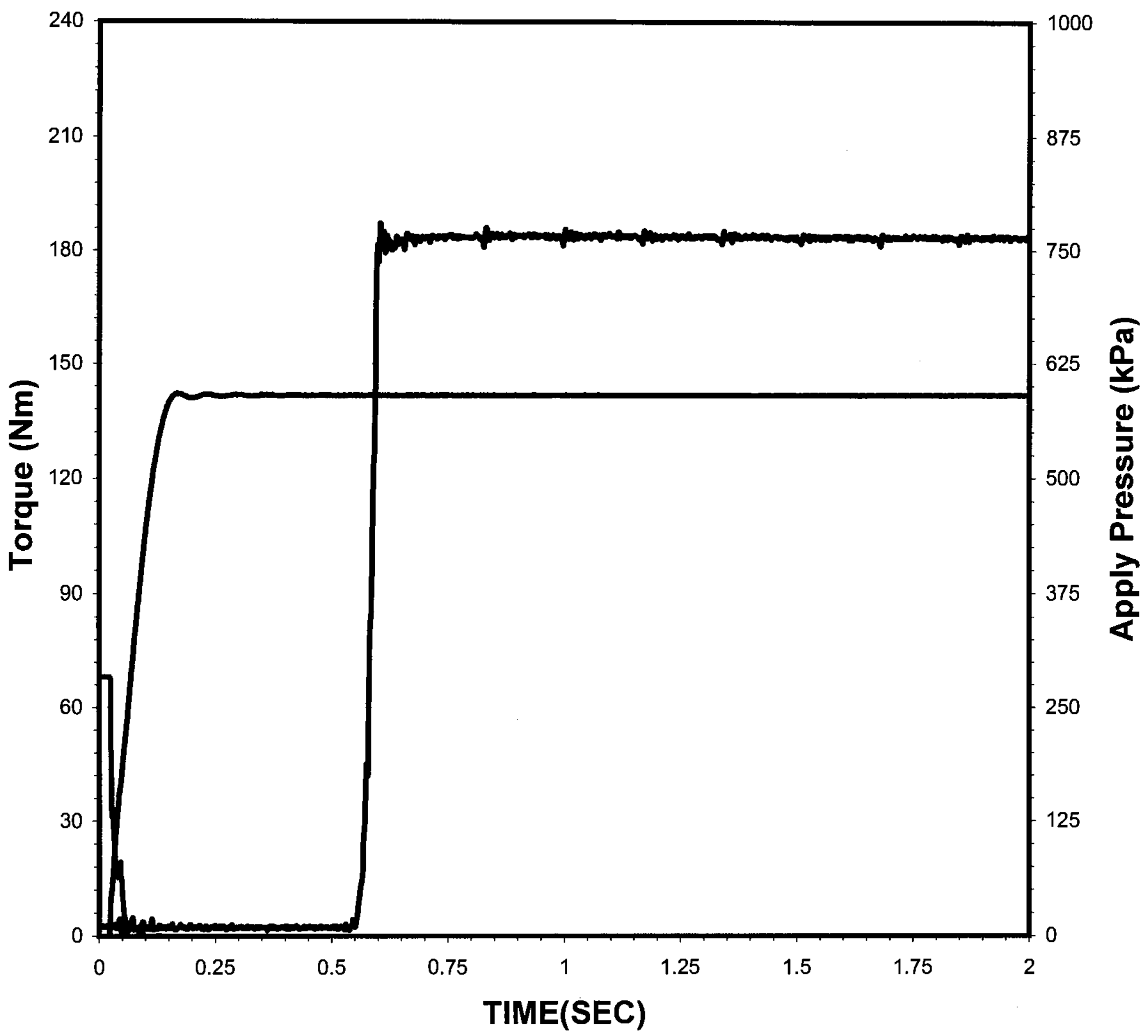
Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 207 Nm
.25 Second: 190 Nm

Coefficient of Friction
Static Peak: 0.143
.25 Second: 0.131

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 6:59:27

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 3500

PHASE B

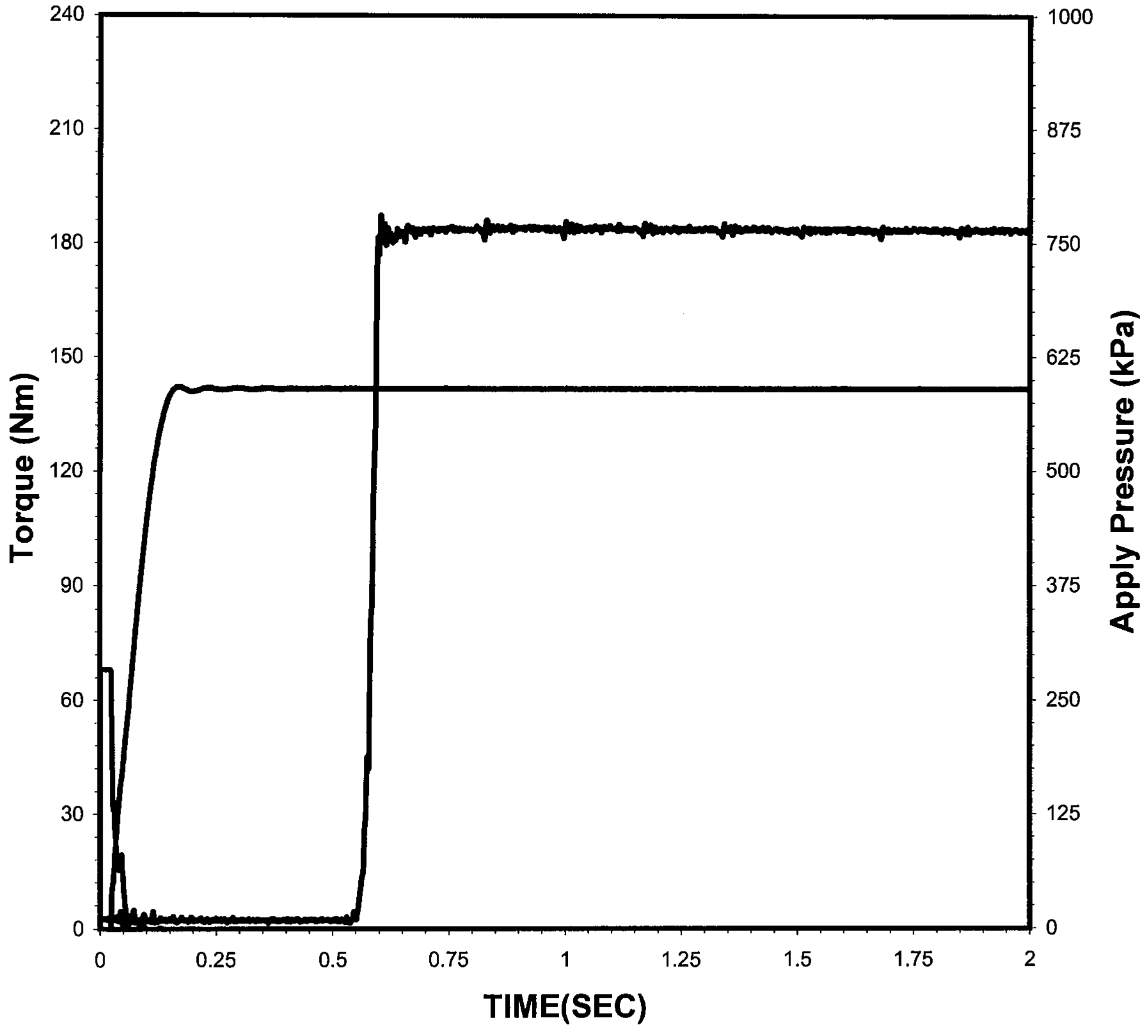
Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 203 Nm
.25 Second: 189 Nm

Coefficient of Friction
Static Peak: 0.140
.25 Second: 0.130

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 9:04:39

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 4000

PHASE B

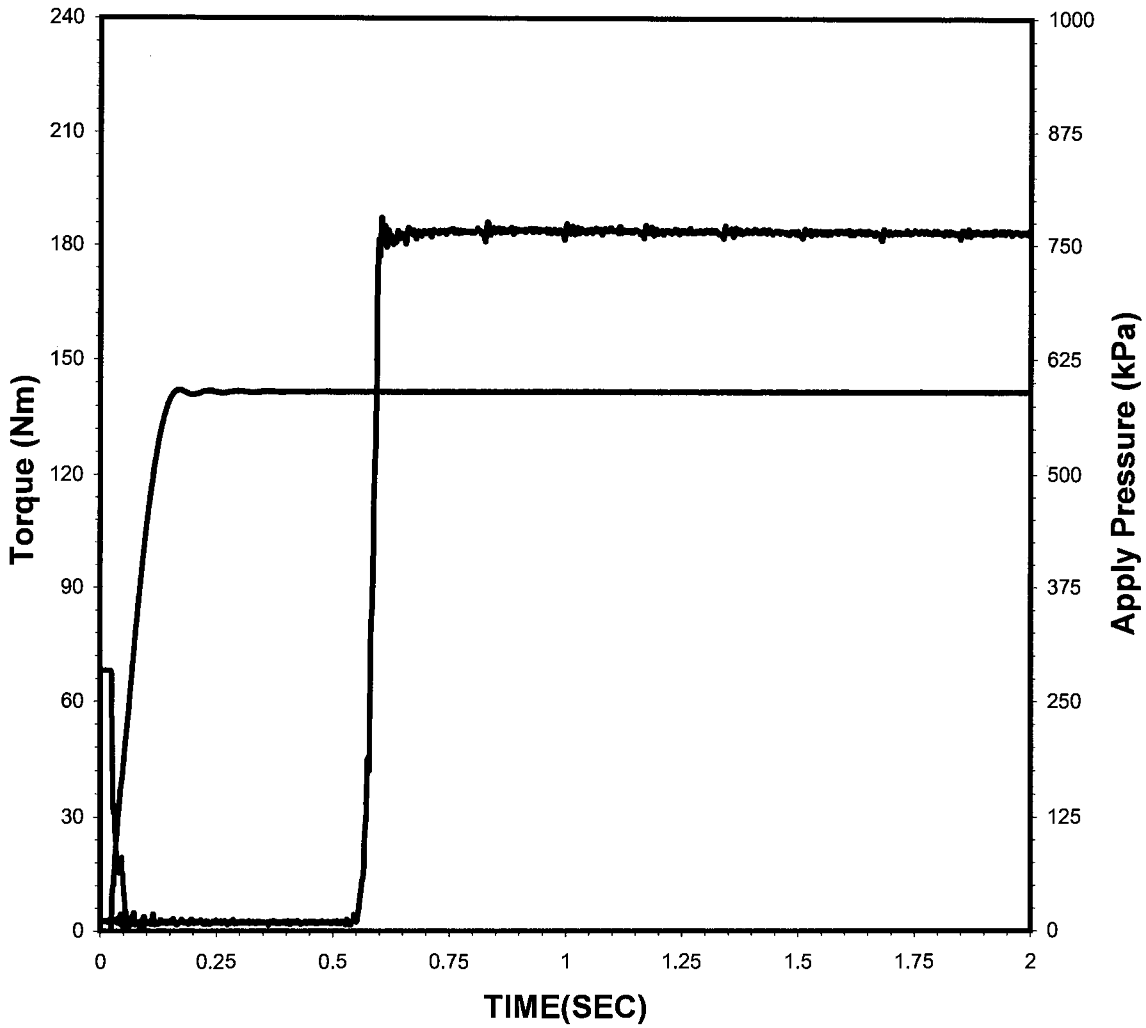
Apply Pressure:
At .25 Second: 829 kPa

Torque
Static Peak: 205 Nm
.25 Second: 188 Nm

Coefficient of Friction
Static Peak: 0.141
.25 Second: 0.130

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 11:09:51

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 4500

PHASE B

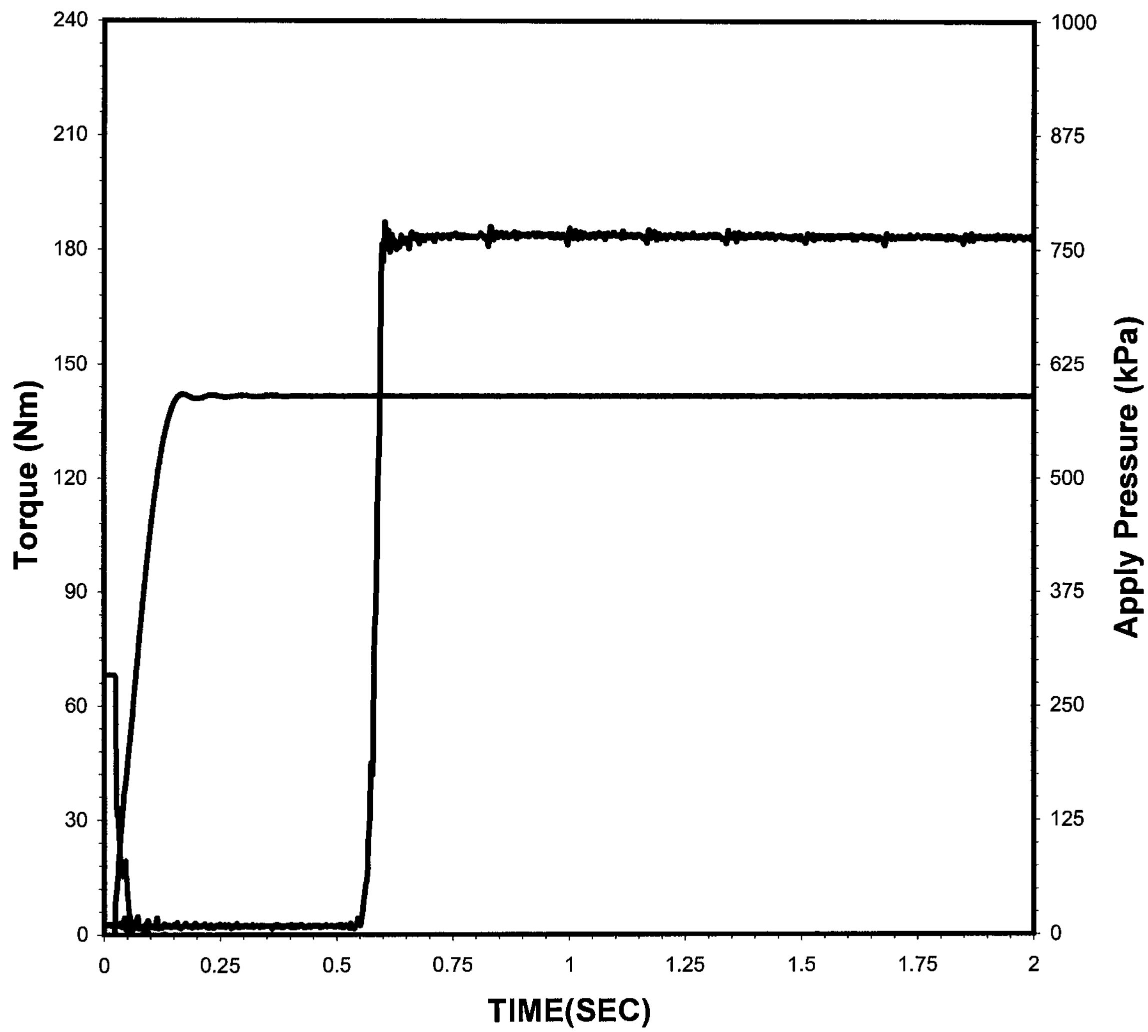
Apply Pressure:
At .25 Second: 828 kPa

Torque
Static Peak: 206 Nm
.25 Second: 187 Nm

Coefficient of Friction
Static Peak: 0.142
.25 Second: 0.129

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 13:15:03

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 5000

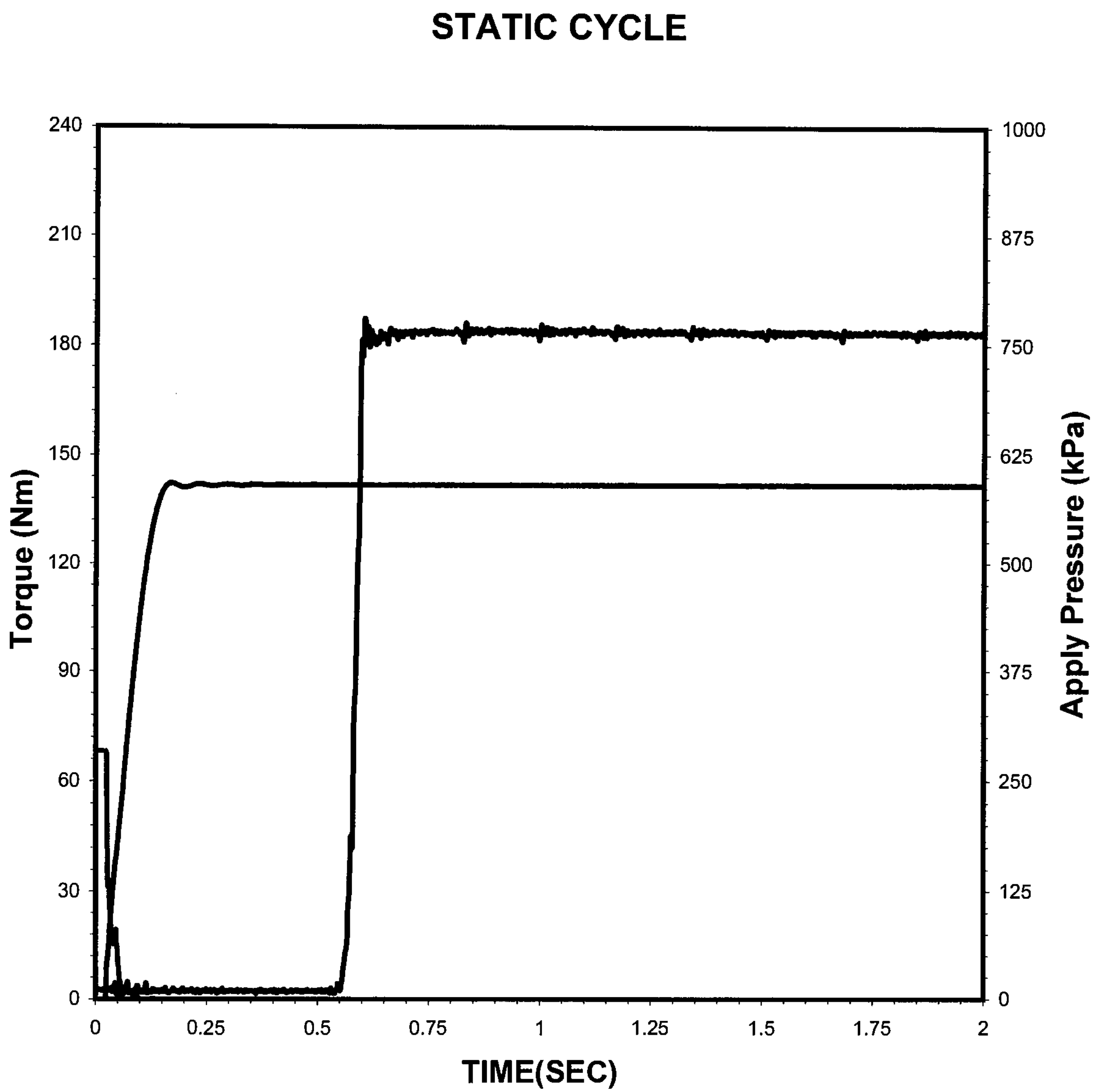
PHASE B

Apply Pressure:
At .25 Second: 828 kPa

Torque
Static Peak: 199 Nm
.25 Second: 189 Nm

Coefficient of Friction
Static Peak: 0.138
.25 Second: 0.131

ALLISON C-4 GRAPHITE DATA



Date of Test: 7/23/2010

Time of Test: 15:20:15

Test Number: C4-9-1287

Fluid Code: LO254054

Cycle Number: 5500

PHASE B

Apply Pressure:
At .25 Second: 827 kPa

Torque
Static Peak: 200 Nm
.25 Second: 186 Nm

Coefficient of Friction
Static Peak: 0.138
.25 Second: 0.129

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted For

ARMY LAB

Oil Code:
LO254054

Test Number:
C2-8-1553

July 26, 2010

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

IX. Paper Clutch Friction Test

Test Laboratory:	SWRI	Lab Fluid Code:	LO-254054
Test Number:	C2-8-1553	Sponsor Fluid Code:	LO-254054
Friction Plate Batch:	BATCH 5	Completion Date:	07/26/10
Steel Plate Batch:	10/9/2008		

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0010	0.0002
Clutch Plate	0.0670	0.0494

	Before	After
Pack Clearance	1.1176	1.3208

Reference Tests

Test Number	Test Date	Test Fluid
C2-0-1523	01/24/09	RDL-2746 08-05
C2-0-1534	11/26/09	RDL-2746 08-05
C2-0-1545	04/03/10	RDL-2746 08-05

	New	EOT
Viscosity at 40°C, cSt	44.43	41.32
Viscosity at 100°C, cSt	8.44	7.91
Iron Content, ppm	2	60

D5185	New Fluid (ppm)
Ba	<1
B	13
Ca	3738
Mg	11
P	1249
Si	13
Na	20
Zn	1969

Name: Matthew Jackson

Signature:

Title: Manager

Date: 8/4/10

ALLISON C- 4 PAPER FRICTION TEST

(Torque in N*m)

Sponsor Fluid Code:	**LO254054**	Test Number:	**C2-8-1553**
Lab Fluid Code:	**254054**	Fric. Plate Batch:	**Batch 5**
Completion Date:	**07/26/2010**	Steel Plate Batch:	**10/9/2008**

TORQUE

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.48	215	260	45	279	270
500	0.43	246	260	14	274	269
1000	0.43	246	260	14	278	273
2500	0.44	239	265	26	278	269
5000	0.44	237	268	31	280	274
7500	0.44	239	270	31	282	274
10000	0.43	242	266	24	285	277

COEFFICIENT OF FRICTION

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.48	0.105	0.127	0.022	0.136	0.131
500	0.43	0.120	0.127	0.007	0.133	0.131
1000	0.43	0.120	0.127	0.007	0.135	0.133
2500	0.44	0.116	0.129	0.013	0.135	0.131
5000	0.44	0.115	0.131	0.016	0.136	0.133
7500	0.44	0.116	0.131	0.015	0.137	0.133
10000	0.43	0.118	0.130	0.012	0.139	0.135

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.480	0.430	-10.42	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.105	0.118	12.38	P
Static Friction Coeff.	N/A	N/A	0.127	0.130	2.36	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.136	0.139	2.21	
0.25 Second Low Speed Coeff.	N/A	N/A	0.131	0.135	3.05	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-PAPER FRICTION TEST

(all units in mm)

Candidate Fluid: LO254054 | **Test Number : C2-8-1553** | **Completion Date : 7/26/2010**

Lab Fluid Code : LO-254054 | **Steel Plate Batch: 10/09/2008** | **Fric Plate Batch : LOT 5**

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.0510	1.9940	2.0380	1.9980	0.0570		0.0400
	120	2.0530	1.9860	2.0370	1.9940	0.0670		0.0430
	240	2.0520	1.9940	2.0400	2.0000	0.0580		0.0400
	Average					0.0607	0.0508	0.0410
5	Top	2.0580	1.9950	2.0430	1.9990	0.0630		0.0440
	120	2.0450	1.9960	2.0460	1.9980	0.0490		0.0480
	240	2.0410	1.9910	2.0320	1.9990	0.0500		0.0330
	Average					0.0540	0.0479	0.0417
STEELS SEPARATORS								
1	Top	1.7540	1.7540	1.7550	1.7550	0.0000		0.0000
	120	1.7510	1.7510	1.7490	1.7480	0.0000		0.0010
	240	1.7510	1.7510	1.7520	1.7520	0.0000		0.0000
	Average					0.0000	0.0002	0.0003
3	Top	1.7570	1.7560	1.7550	1.7550	0.0010		0.0000
	120	1.7550	1.7550	1.7540	1.7540	0.0000		0.0000
	240	1.7540	1.7540	1.7540	1.7540	0.0000		0.0000
	Average					0.0003	0.0002	0.0000
4	Top	1.7540	1.7540	1.7540	1.7540	0.0000		0.0000
	120	1.7520	1.7520	1.7510	1.7510	0.0000		0.0000
	240	1.7520	1.7520	1.7520	1.7520	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
6	Top	1.7530	1.7530	1.7500	1.7500	0.0000		0.0000
	120	1.7540	1.7530	1.7530	1.7530	0.0010		0.0000
	240	1.7530	1.7530	1.7530	1.7520	0.0000		0.0010
	Average					0.0003	0.0003	0.0003

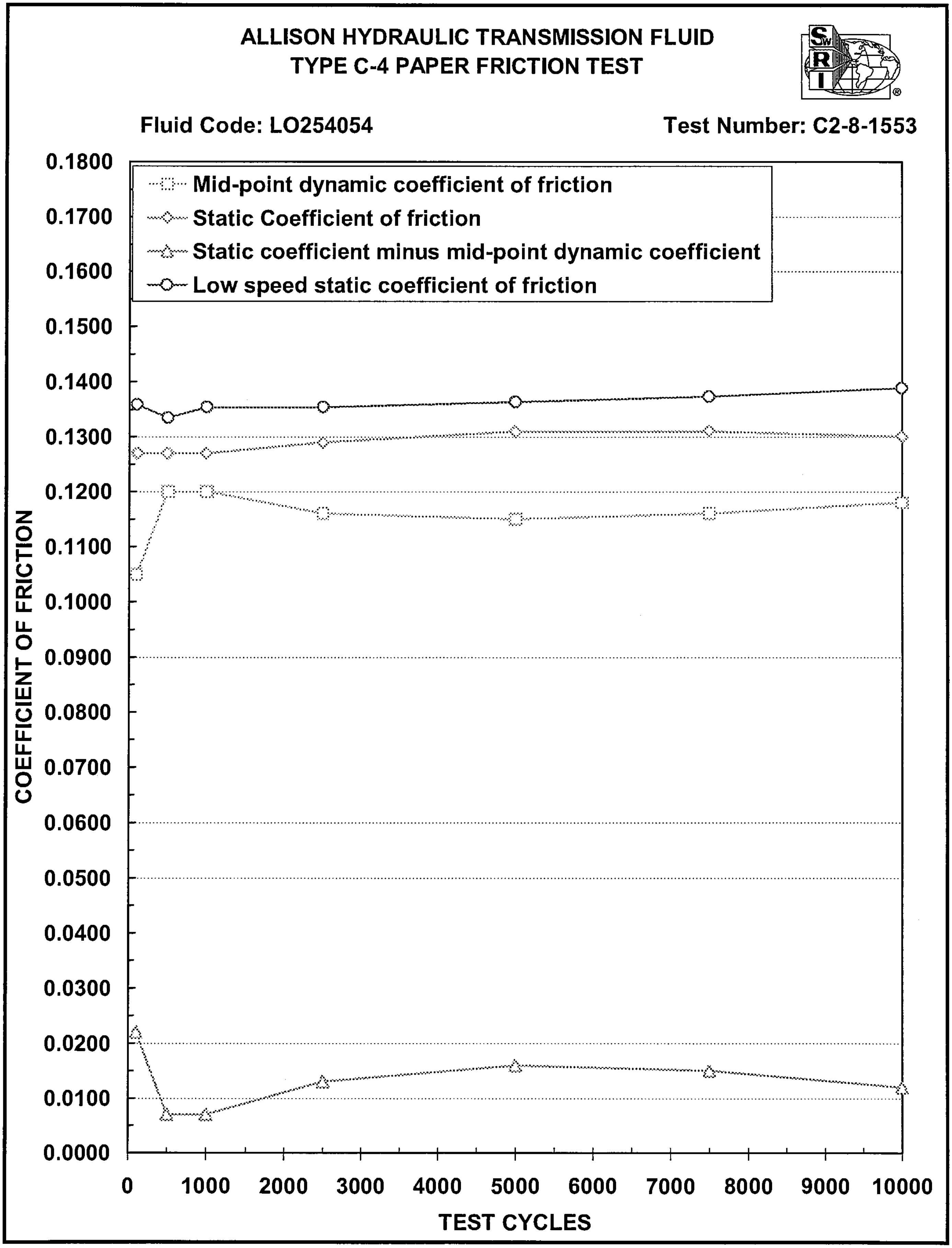
PLATE CONDITION AT E.O.T.: PLATES IN GOOD CONDITION WITH LIGHT DISCOLORATION ON INNER STEEL
(Anything Unusual) PLATES. MICROMETER #0153667

Test Date and Operator's Name: 7/26/2010 MARK HOLMES

Reviewed By (Signature and Date)

8/4/10

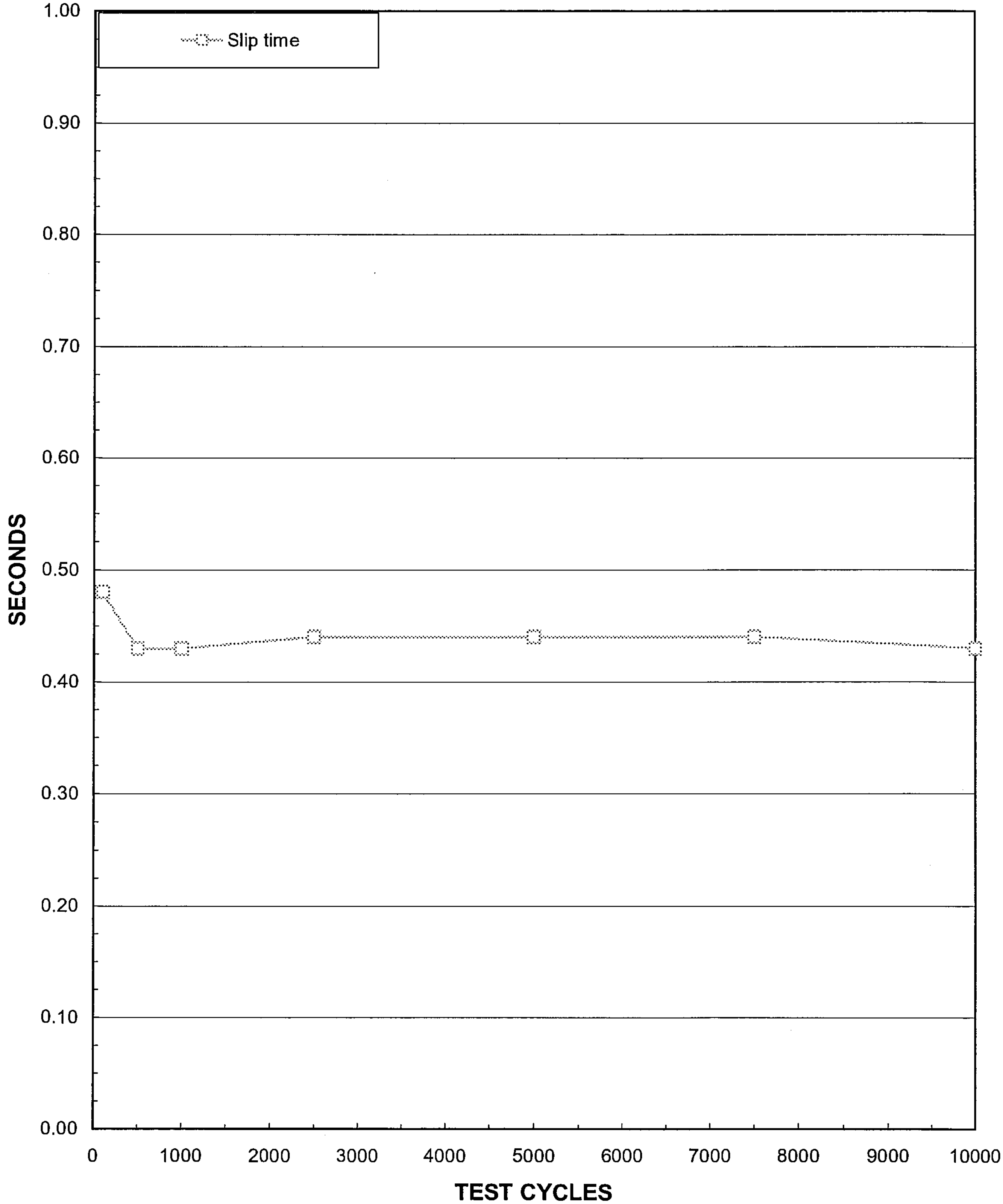
Pack ID#: 4436

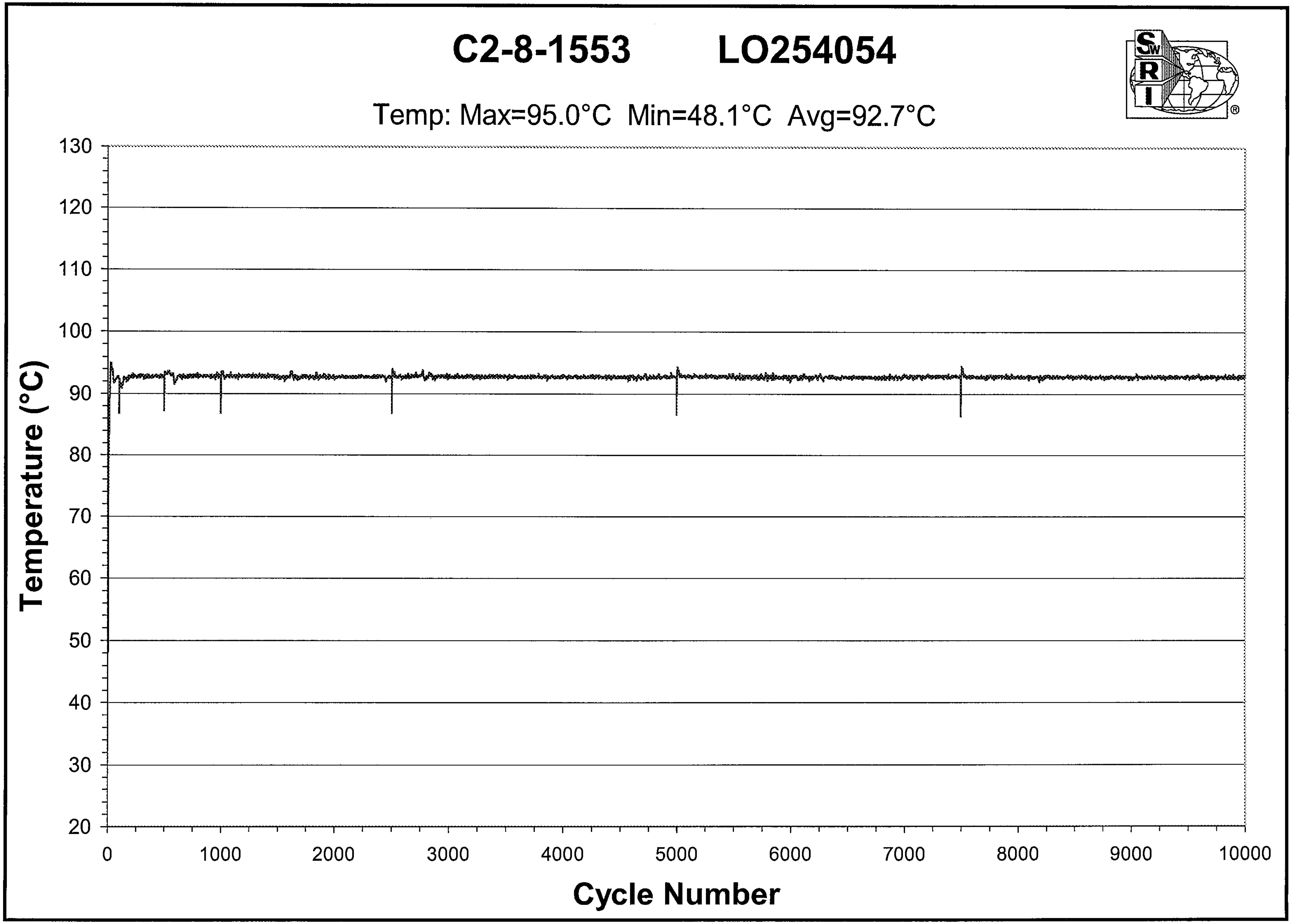


ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO254054
Test Number: C2-8-1553
Mid-point dynamic coefficient of friction
Static Coefficient of friction
Static coefficient minus mid-point dynamic coefficient
Low speed static coefficient of friction
COEFFICIENT OF FRICTION
0.1800
0.1700
0.1600
0.1500
0.1400
0.1300
0.1200
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0.0200
0.0100
0.0000
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
TEST CYCLES

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST

Fluid Code: LO254054 **Test Number: C2-8-1553**



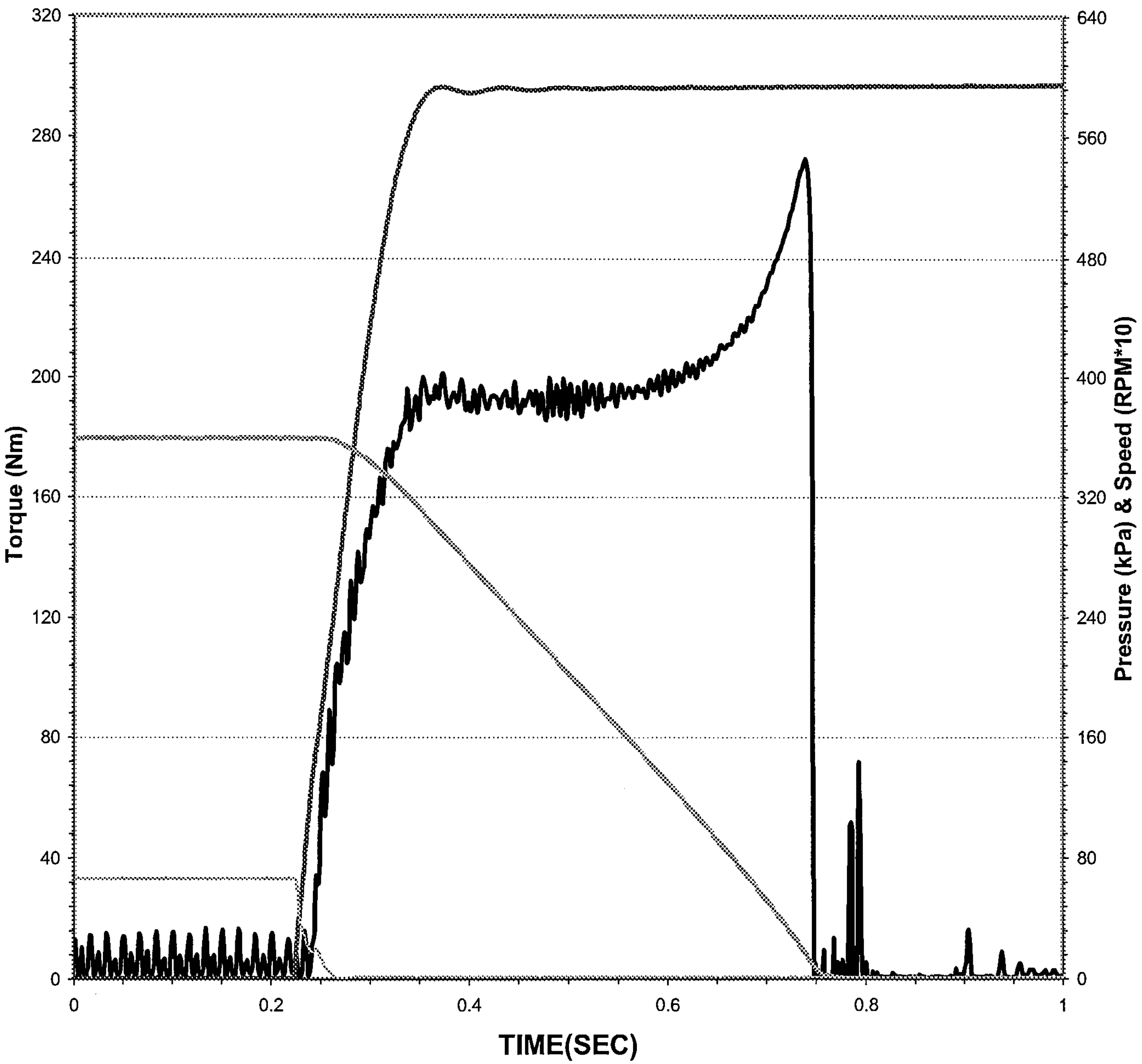


C2-8-1553 LO254054
Temp: Max=95.0°C Min=48.1°C Avg=92.7°C
Temperature (°C)
130
120
110
100
90
80
70
60
50
40
30
20
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cycle Number

DYNAMIC TRACES

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/25/2010
Time of Test:	3:13:34
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	10
Temperature:	83.6 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	591 kPa
	(586 ± 7 KPa)
Apply Rate:	0.14 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.523 Sec

Torque

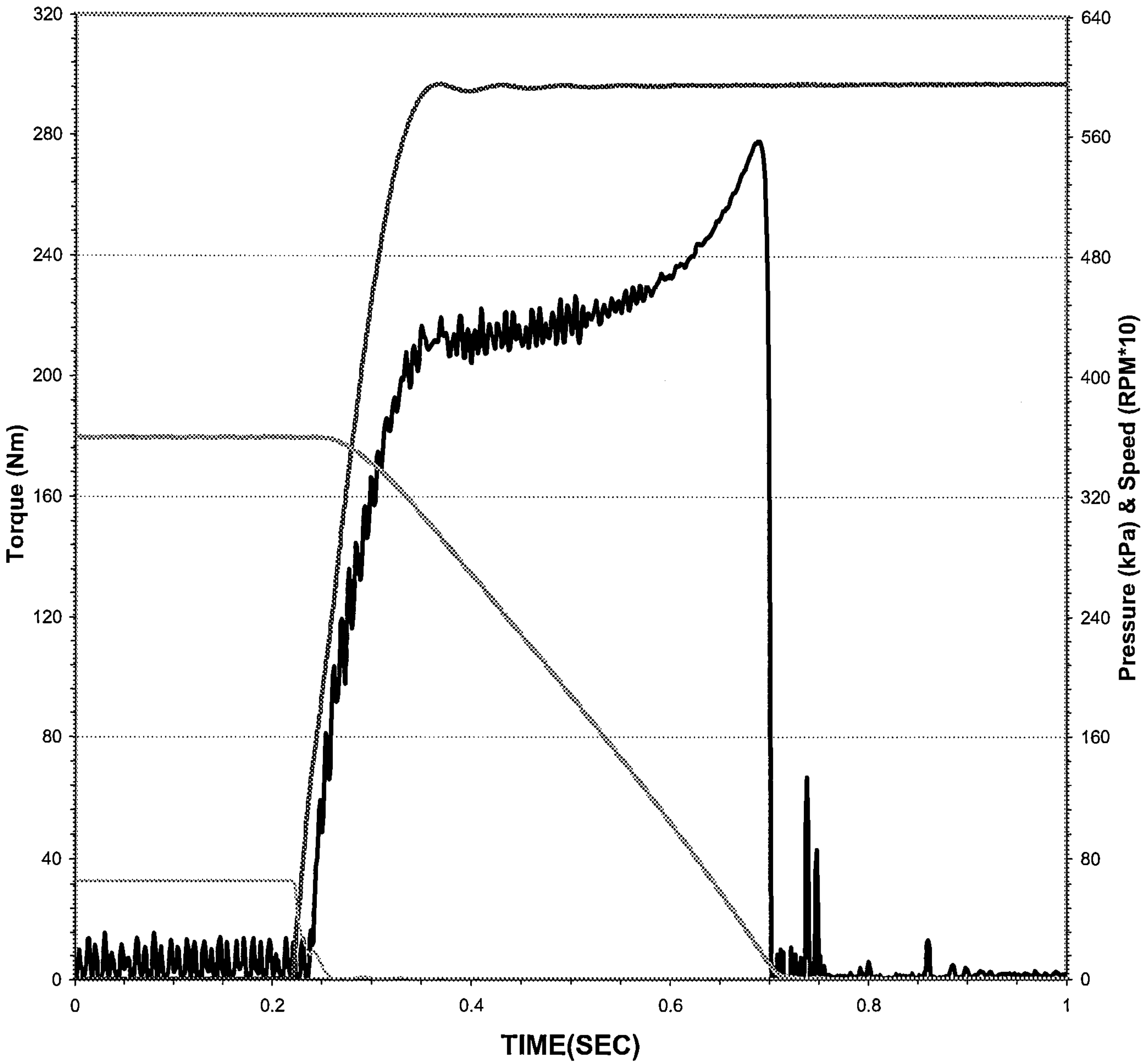
0.2 Sec Dyn:	191 N*m
Midpoint Dyn:	191 N*m
LwSpd Dynamic:	259 N*m

Coefficient of Friction

.2 Sec Dyn:	0.093
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.126

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/25/2010
Time of Test:	3:36:05
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	99
Temperature:	92.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	592 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.479 Sec

Torque

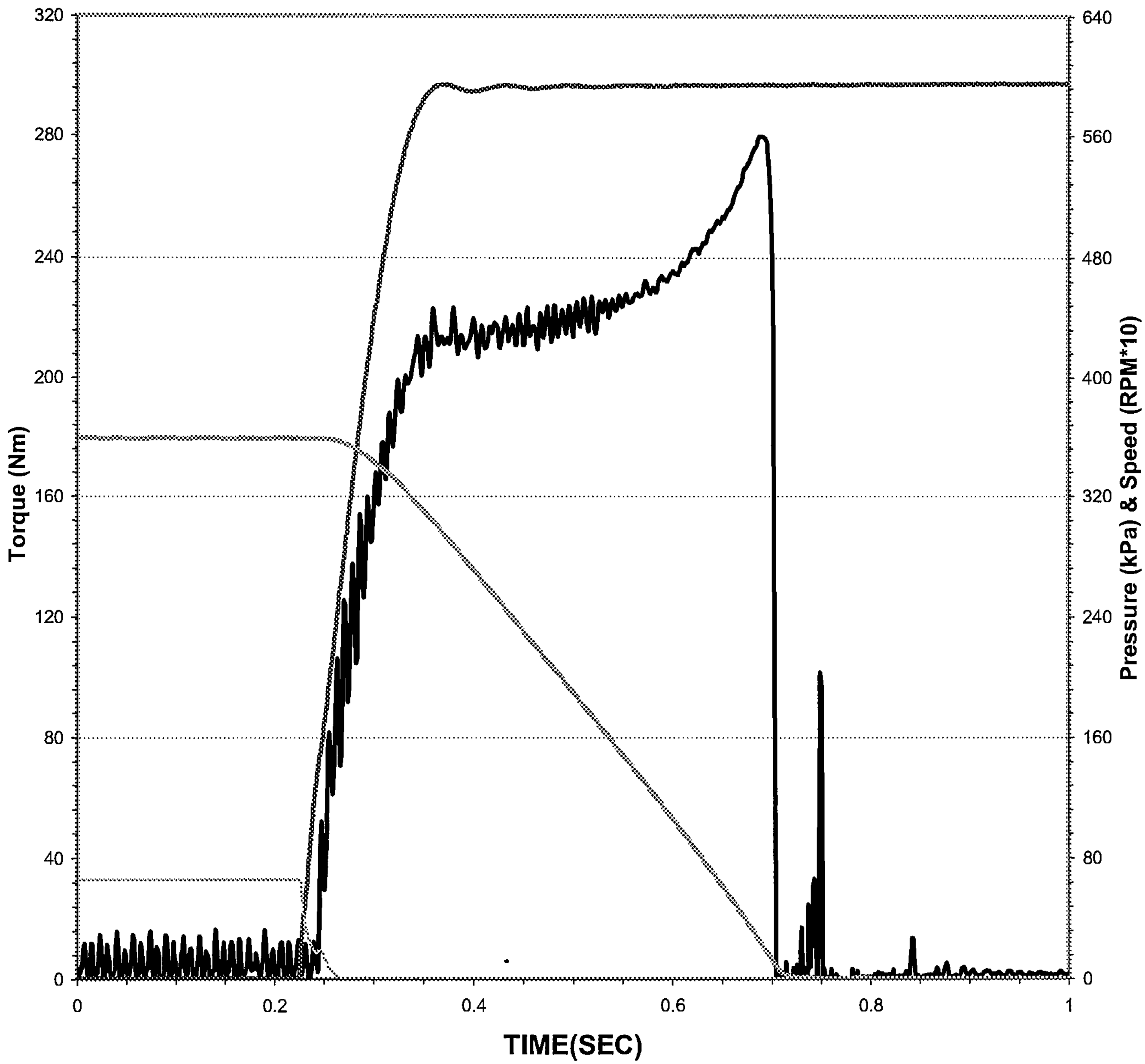
0.2 Sec Dyn:	212 N*m
Midpoint Dyn:	214 N*m
LwSpd Dynamic:	257 N*m

Coefficient of Friction

.2 Sec Dyn:	0.103
Midpoint Dyn:	0.104
LwSpd Dynamic:	0.125

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/25/2010

Time of Test: 3:36:20

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 100

Temperature: 92.5 °C (93.3 ± 3.0 °C)

Apply Pressure: 592 kPa (586 ± 7 KPa)

Apply Rate: 0.13 Sec (0.15 ± 0.02 Sec)

Energy: 18.6 KJ (18.7 ± 0.40 KJ)

Engage Time: 0.478 Sec

Torque

0.2 Sec Dyn: 214 N*m

Midpoint Dyn: 215 N*m

LwSpd Dynamic: 263 N*m

Coefficient of Friction

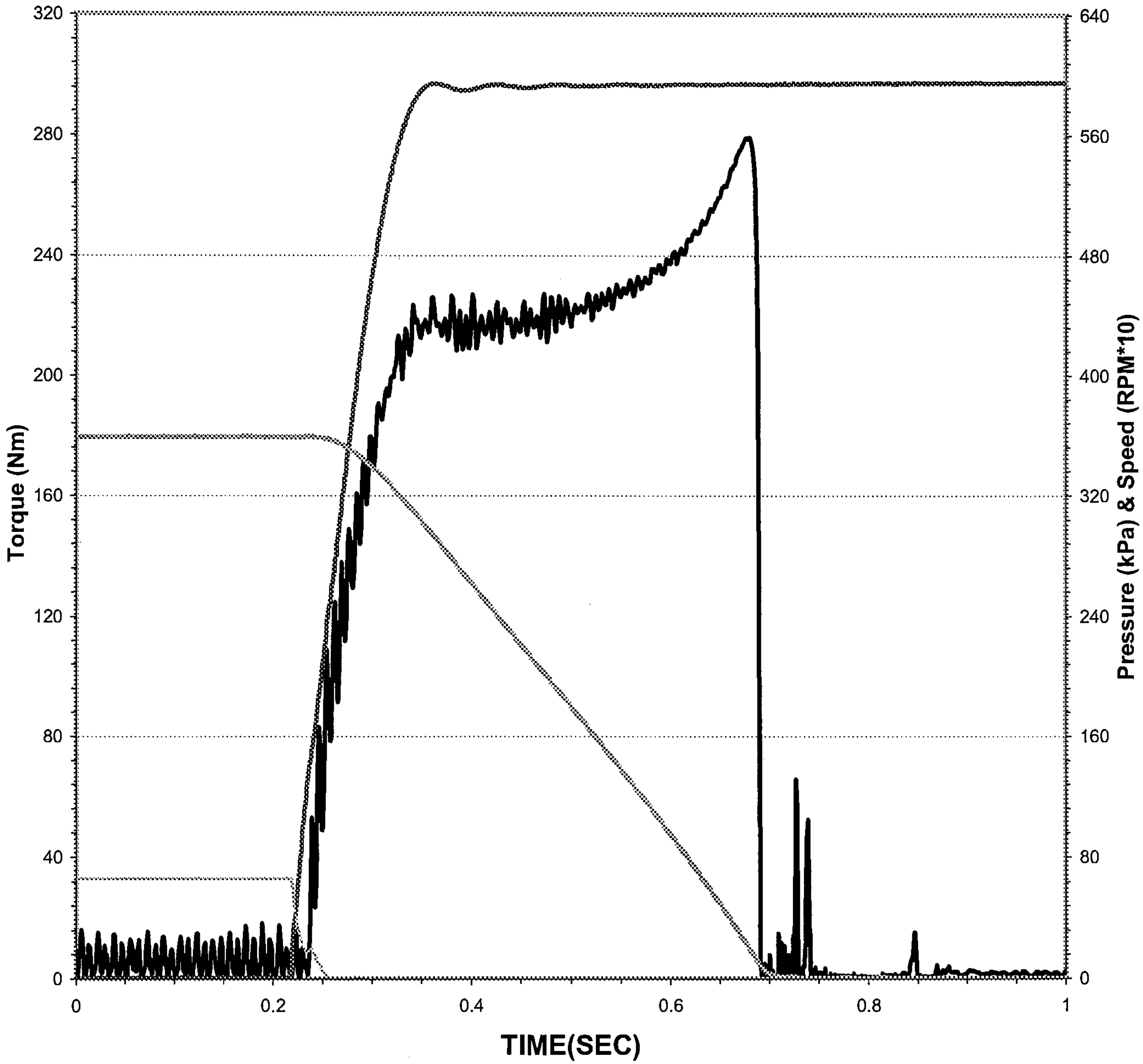
.2 Sec Dyn: 0.104

Midpoint Dyn: 0.105

LwSpd Dynamic: 0.128

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/25/2010
Time of Test:	3:36:51
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	101
Temperature:	86.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	592 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.473 Sec

Torque

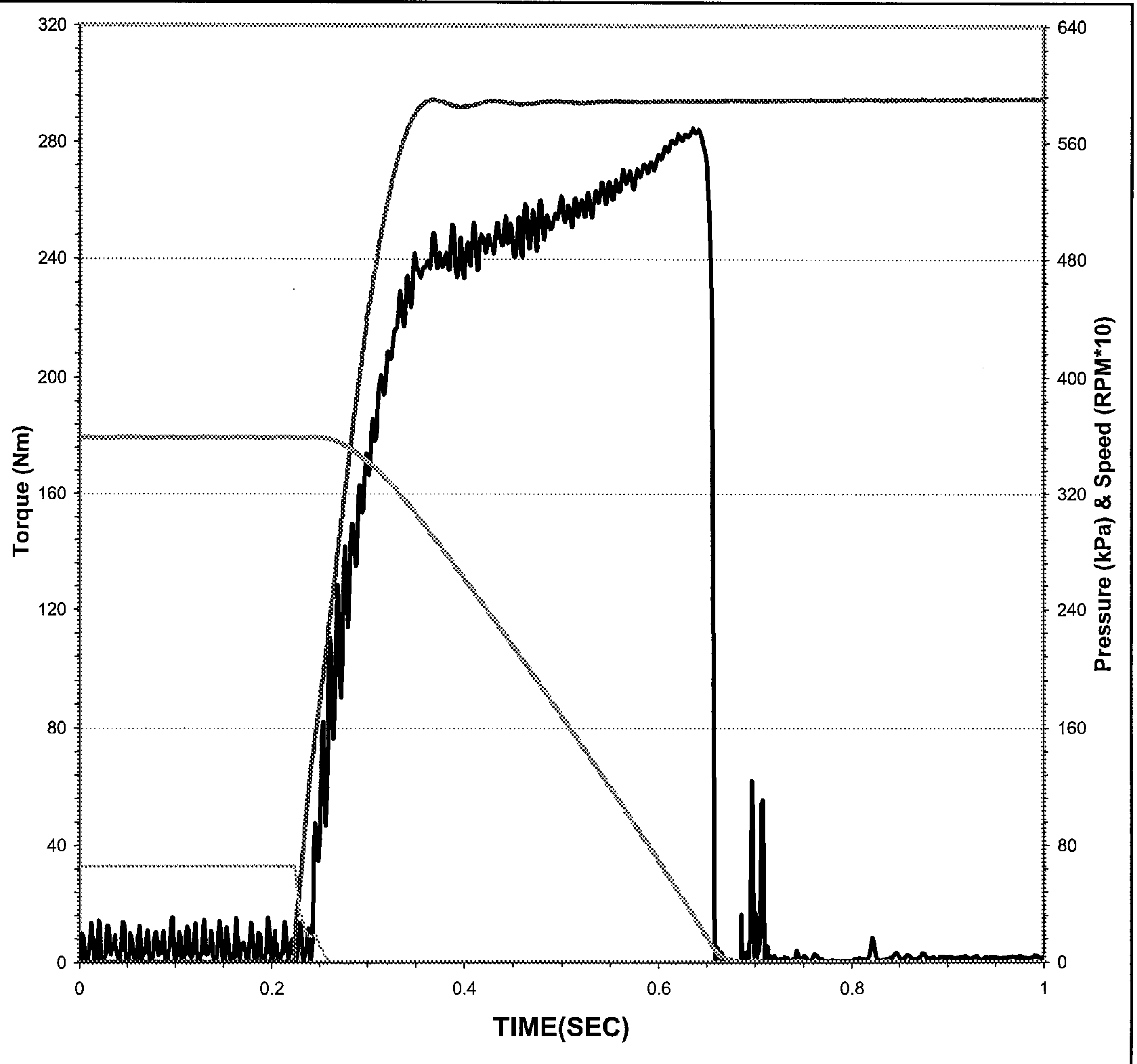
0.2 Sec Dyn:	215 N*m
Midpoint Dyn:	216 N*m
LwSpd Dynamic:	262 N*m

Coefficient of Friction

.2 Sec Dyn:	0.105
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.127

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/25/2010
Time of Test:	5:16:21
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	499
Temperature:	92.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	587 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.435 Sec

Torque

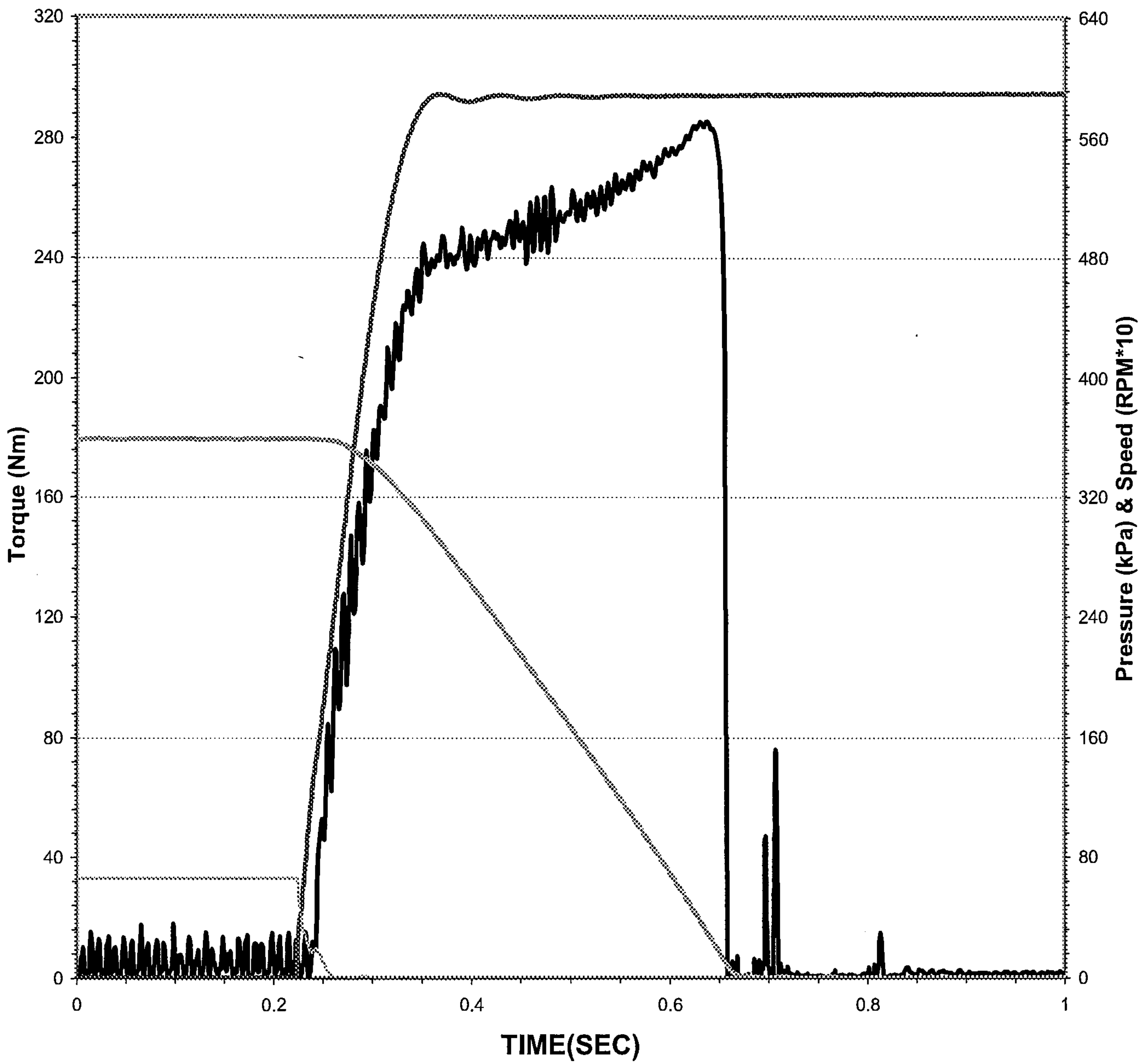
0.2 Sec Dyn:	244 N*m
Midpoint Dyn:	245 N*m
LwSpd Dynamic:	259 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.126

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/25/2010

Time of Test: 5:16:36

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 500

Temperature: 92.5 °C (93.3 ± 3.0 °C)

Apply Pressure: 587 kPa (586 ± 7 KPa)

Apply Rate: 0.13 Sec (0.15 ± 0.02 Sec)

Energy: 18.6 KJ (18.7 ± 0.40 KJ)

Engage Time: 0.434 Sec

Torque

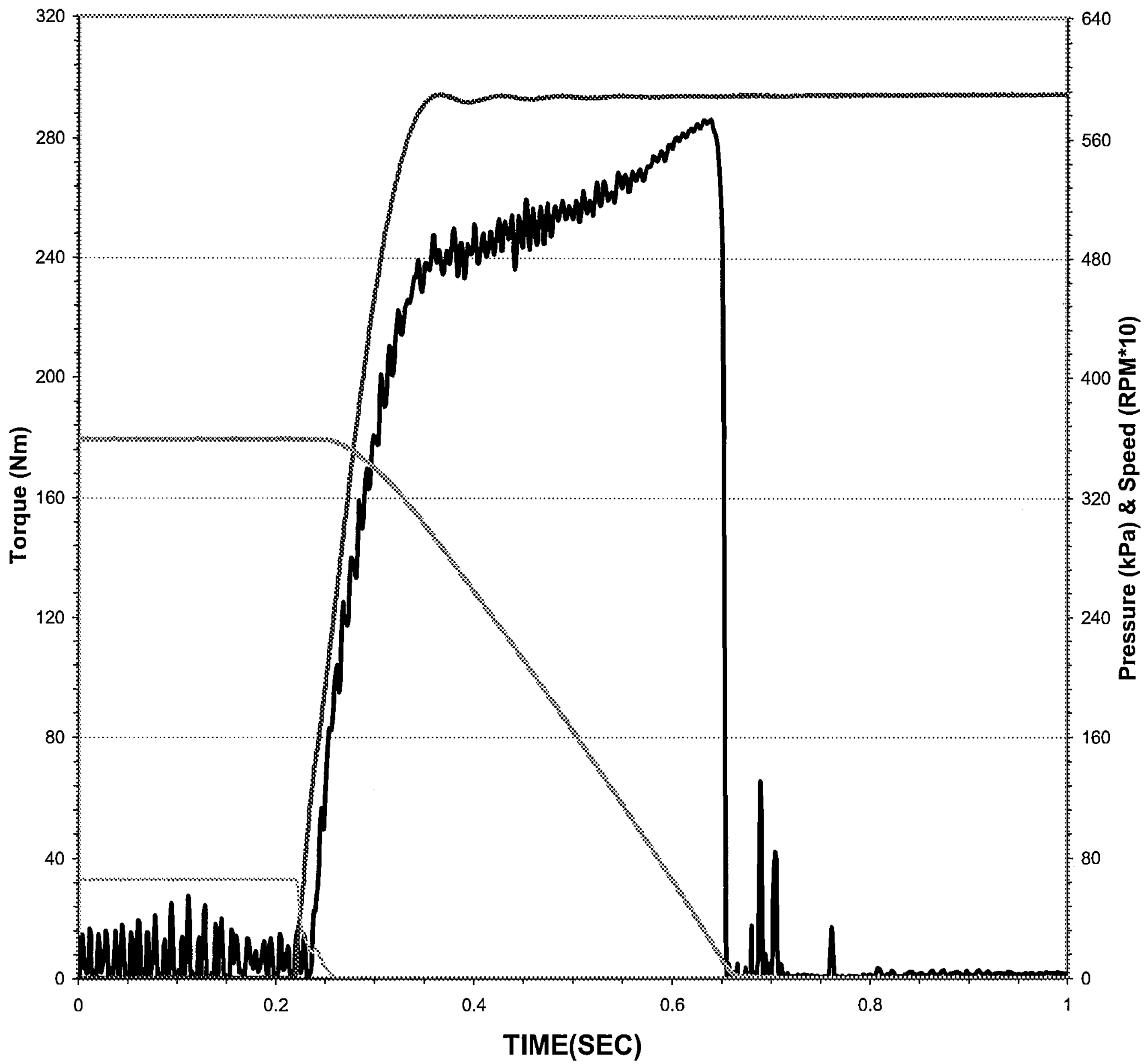
0.2 Sec Dyn:	244 N*m
Midpoint Dyn:	246 N*m
LwSpd Dynamic:	258 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.126

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/25/2010

Time of Test: 5:17:07

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 501

Temperature: 87.2 °C
(93.3 ± 3.0 °C)

Apply Pressure: 587 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.7 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.434 Sec

Torque

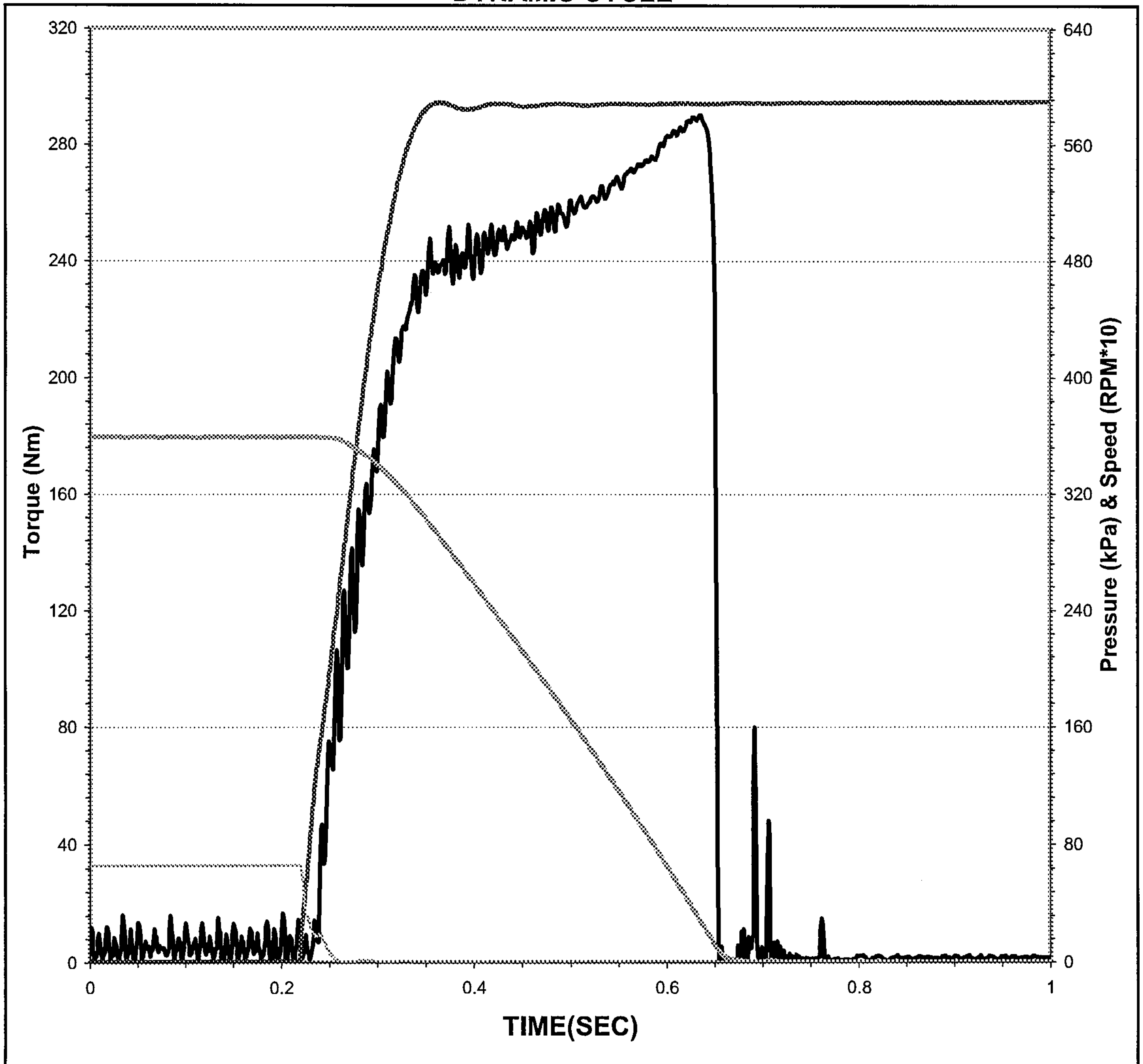
0.2 Sec Dyn: 245 N*m
Midpoint Dyn: 246 N*m
LwSpd Dynamic: 264 N*m

Coefficient of Friction

.2 Sec Dyn: 0.119
Midpoint Dyn: 0.120
LwSpd Dynamic: 0.128

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/25/2010

Time of Test: 7:21:37

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 999

Temperature: 92.8 °C
(93.3 ± 3.0 °C)

Apply Pressure: 587 kPa
(586 ± 7 KPa)

Apply Rate: 0.14 Sec
(0.15 ± 0.02 Sec)

Energy: 18.7 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.434 Sec

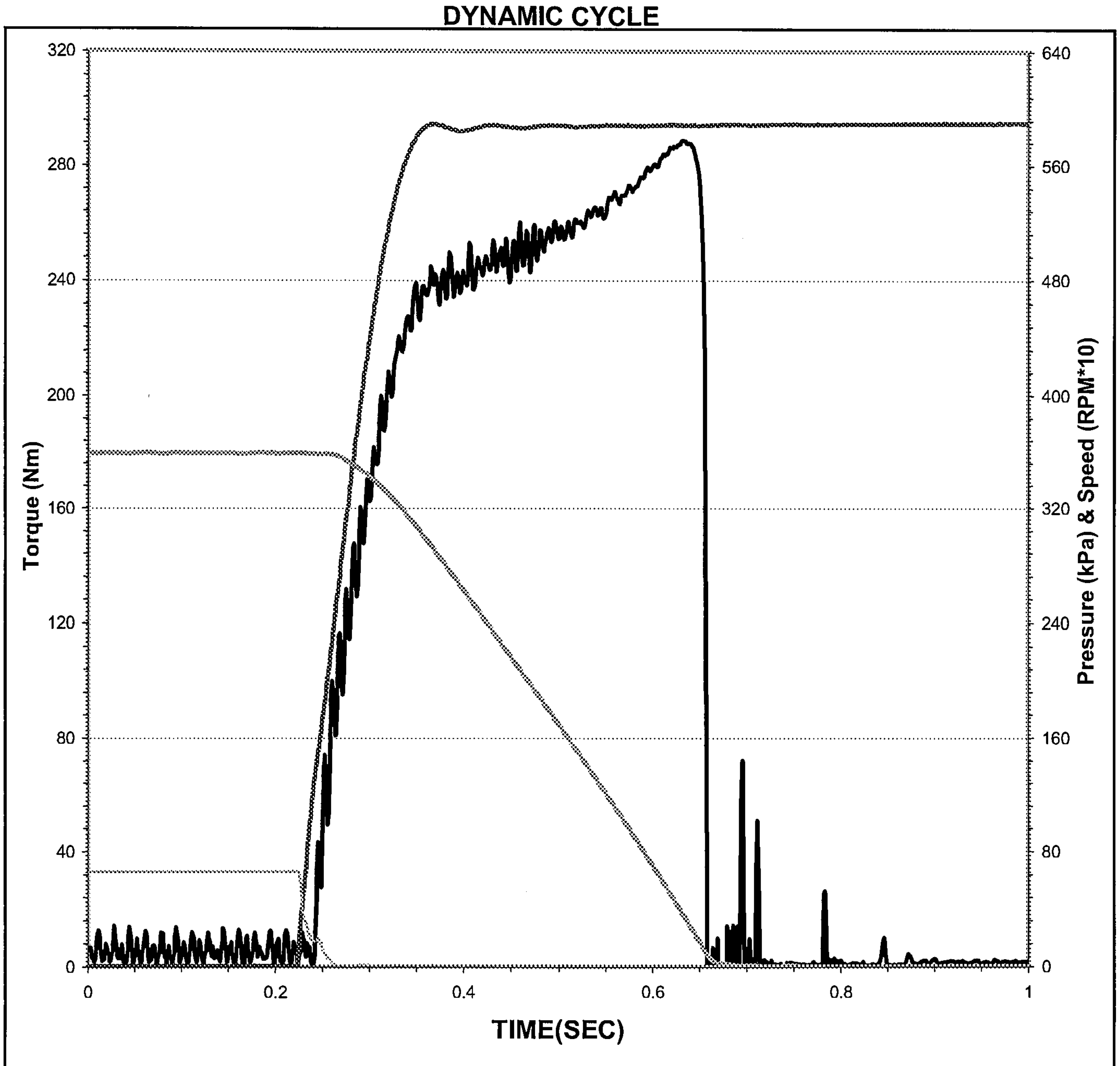
Torque

0.2 Sec Dyn: 245 N*m
Midpoint Dyn: 247 N*m
LwSpd Dynamic: 258 N*m

Coefficient of Friction

.2 Sec Dyn: 0.119
Midpoint Dyn: 0.120
LwSpd Dynamic: 0.126

ALLISON C-4 PAPER DATA



Date of Test: 7/25/2010

Time of Test: 7:21:52

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 1000

Temperature: 92.6 °C
(93.3 ± 3.0 °C)

Apply Pressure: 587 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.7 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.433 Sec

Torque

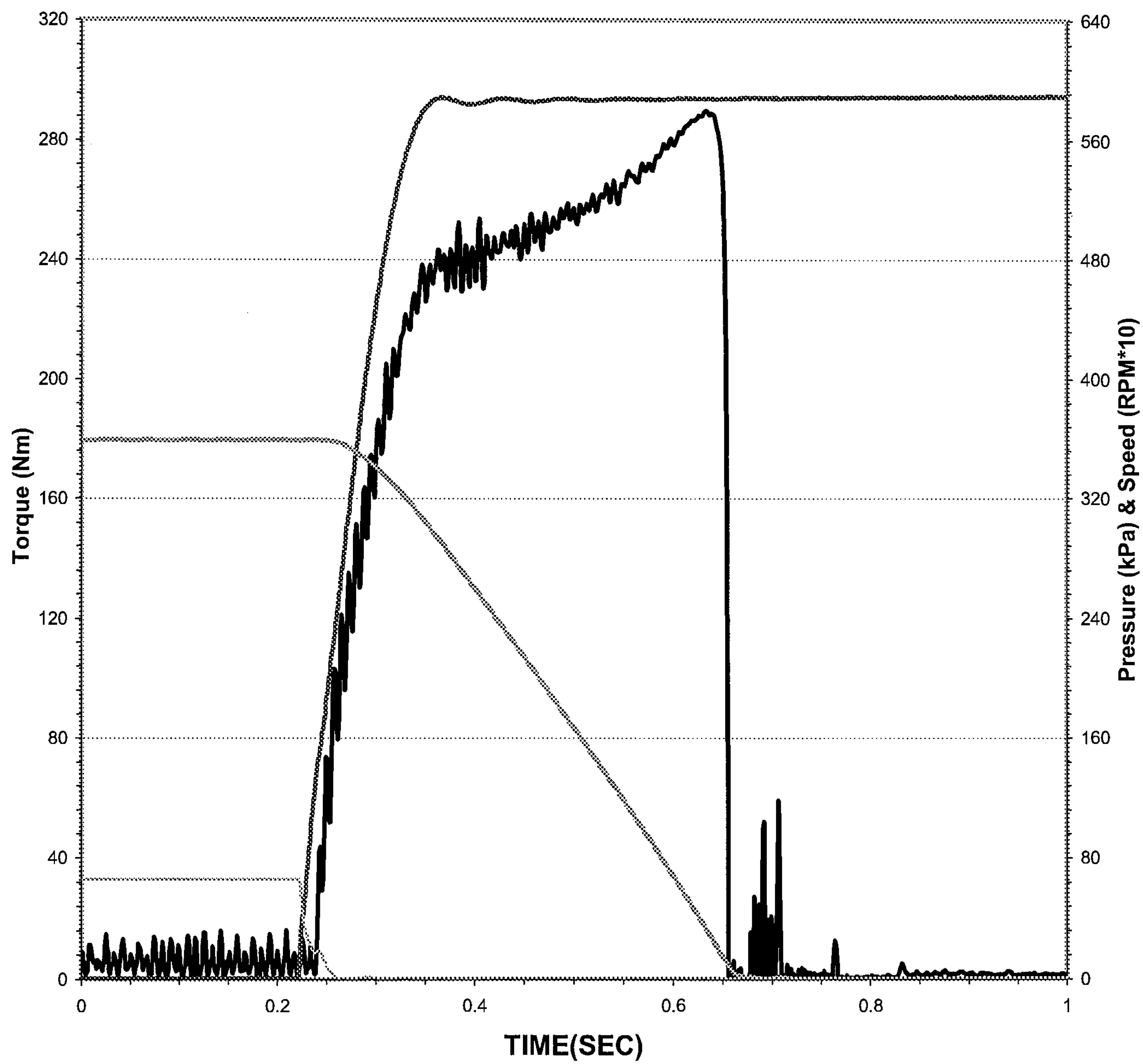
0.2 Sec Dyn:	245 N*m
Midpoint Dyn:	246 N*m
LwSpd Dynamic:	261 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.127

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/25/2010

Time of Test: 7:22:24

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 1001

Temperature: 86.7 °C (93.3 ± 3.0 °C)

Apply Pressure: 587 kPa (586 ± 7 KPa)

Apply Rate: 0.14 Sec (0.15 ± 0.02 Sec)

Energy: 18.7 KJ (18.7 ± 0.40 KJ)

Engage Time: 0.433 Sec

Torque

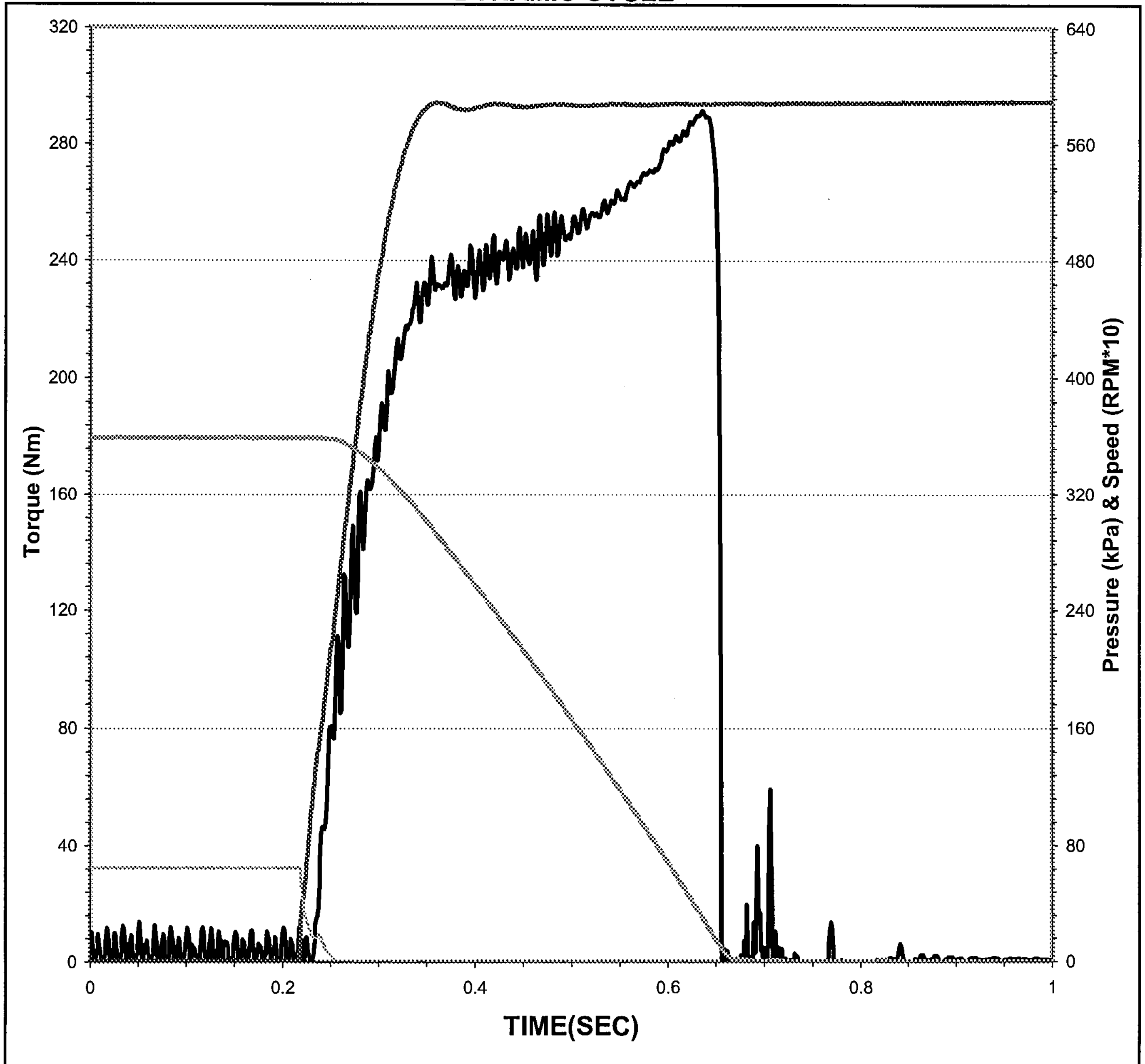
0.2 Sec Dyn:	243 N*m
Midpoint Dyn:	244 N*m
LwSpd Dynamic:	262 N*m

Coefficient of Friction

.2 Sec Dyn:	0.118
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.128

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/25/2010

Time of Test: 13:36:54

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 2499

Temperature: 92.5 °C
(93.3 ± 3.0 °C)

Apply Pressure: 586 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.7 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.438 Sec

Torque

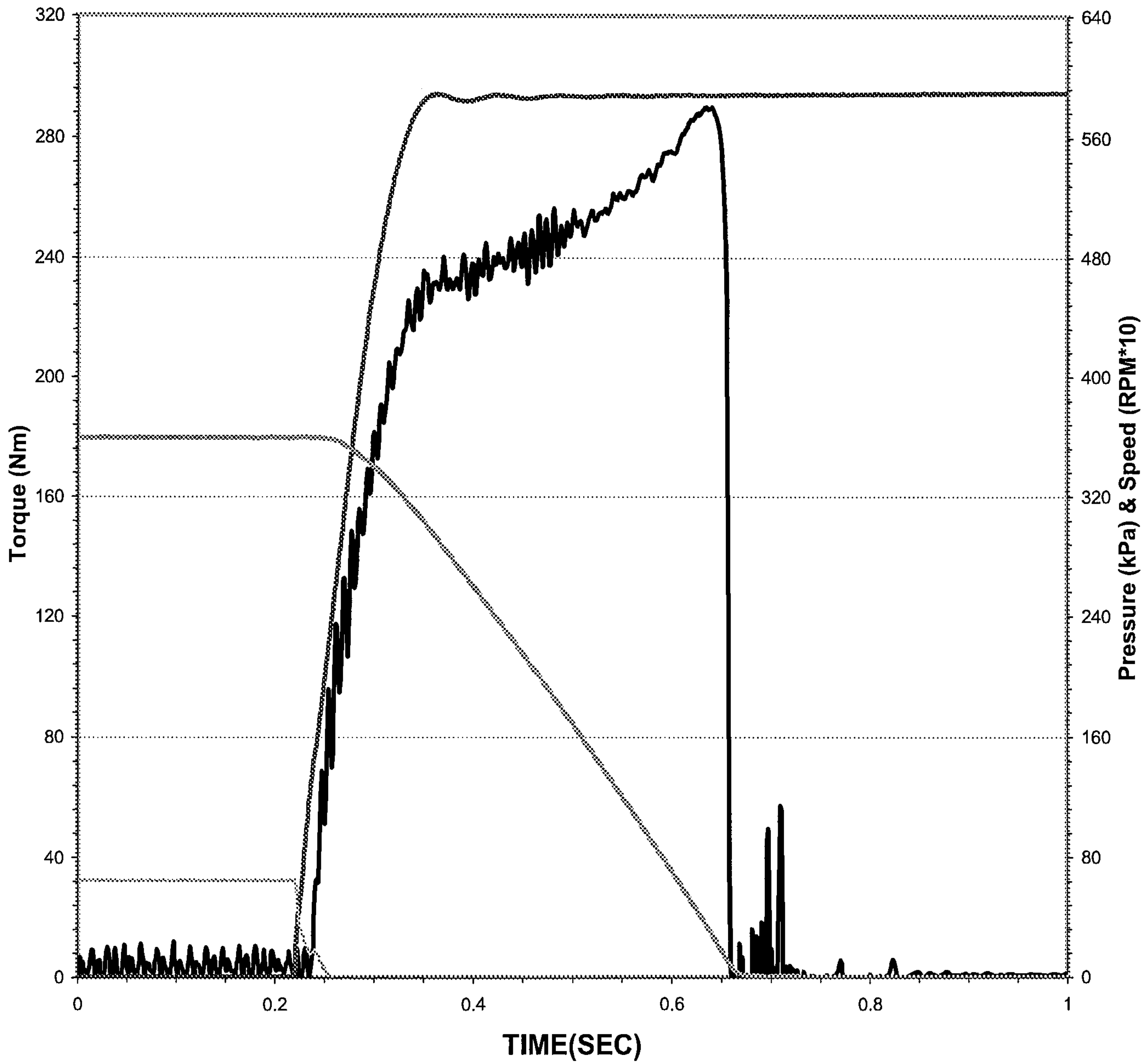
0.2 Sec Dyn: 240 N*m
Midpoint Dyn: 241 N*m
LwSpd Dynamic: 266 N*m

Coefficient of Friction

.2 Sec Dyn: 0.117
Midpoint Dyn: 0.117
LwSpd Dynamic: 0.129

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/25/2010
Time of Test:	13:37:09
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	2500
Temperature:	92.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.438 Sec

Torque

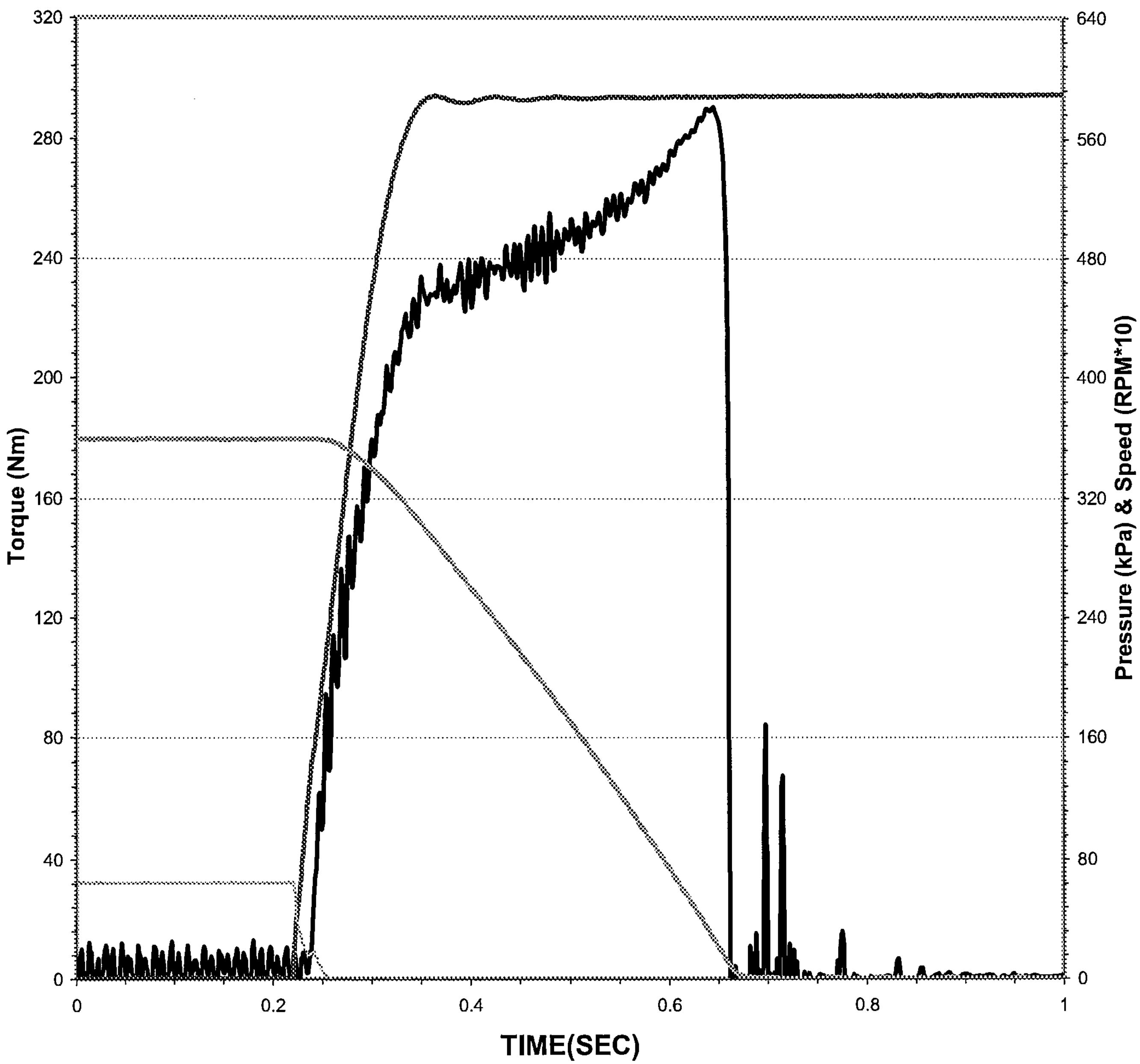
0.2 Sec Dyn:	237 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	265 N*m

Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.129

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/25/2010
Time of Test:	13:37:40
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	2501
Temperature:	86.8 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.441 Sec

Torque

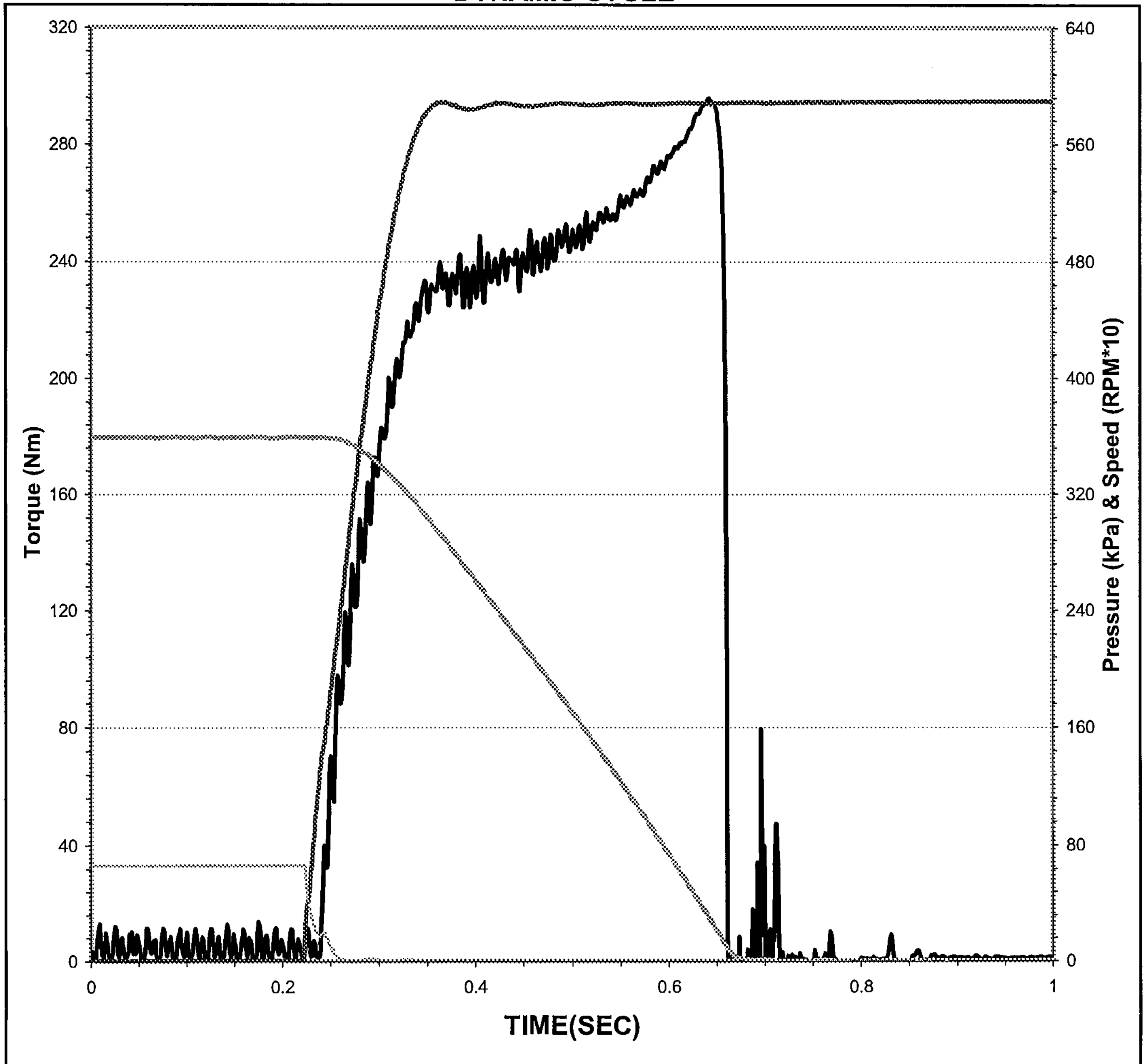
0.2 Sec Dyn:	235 N*m
Midpoint Dyn:	237 N*m
LwSpd Dynamic:	265 N*m

Coefficient of Friction

.2 Sec Dyn:	0.114
Midpoint Dyn:	0.115
LwSpd Dynamic:	0.129

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/26/2010
Time of Test:	0:02:10
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	4999
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.439 Sec

Torque

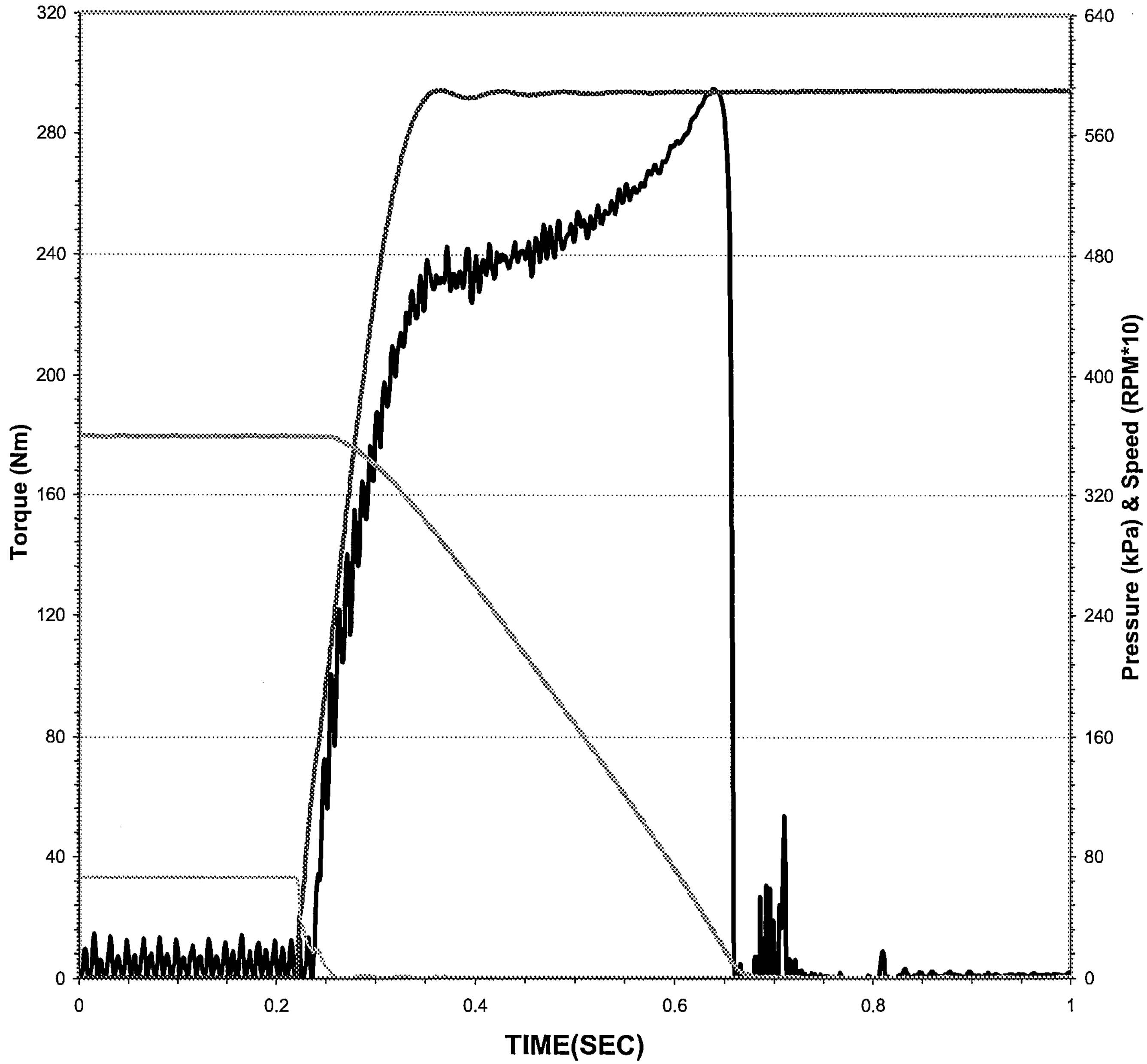
0.2 Sec Dyn:	236 N*m
Midpoint Dyn:	238 N*m
LwSpd Dynamic:	271 N*m

Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.132

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/26/2010**
Time of Test:	**0:02:25**
Test Number:	**C2-8-1553**
Fluid Code:	**LO254054**
Cycle Number:	**5000**
Temperature:	**92.7 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**586 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.7 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.439 Sec**

Torque

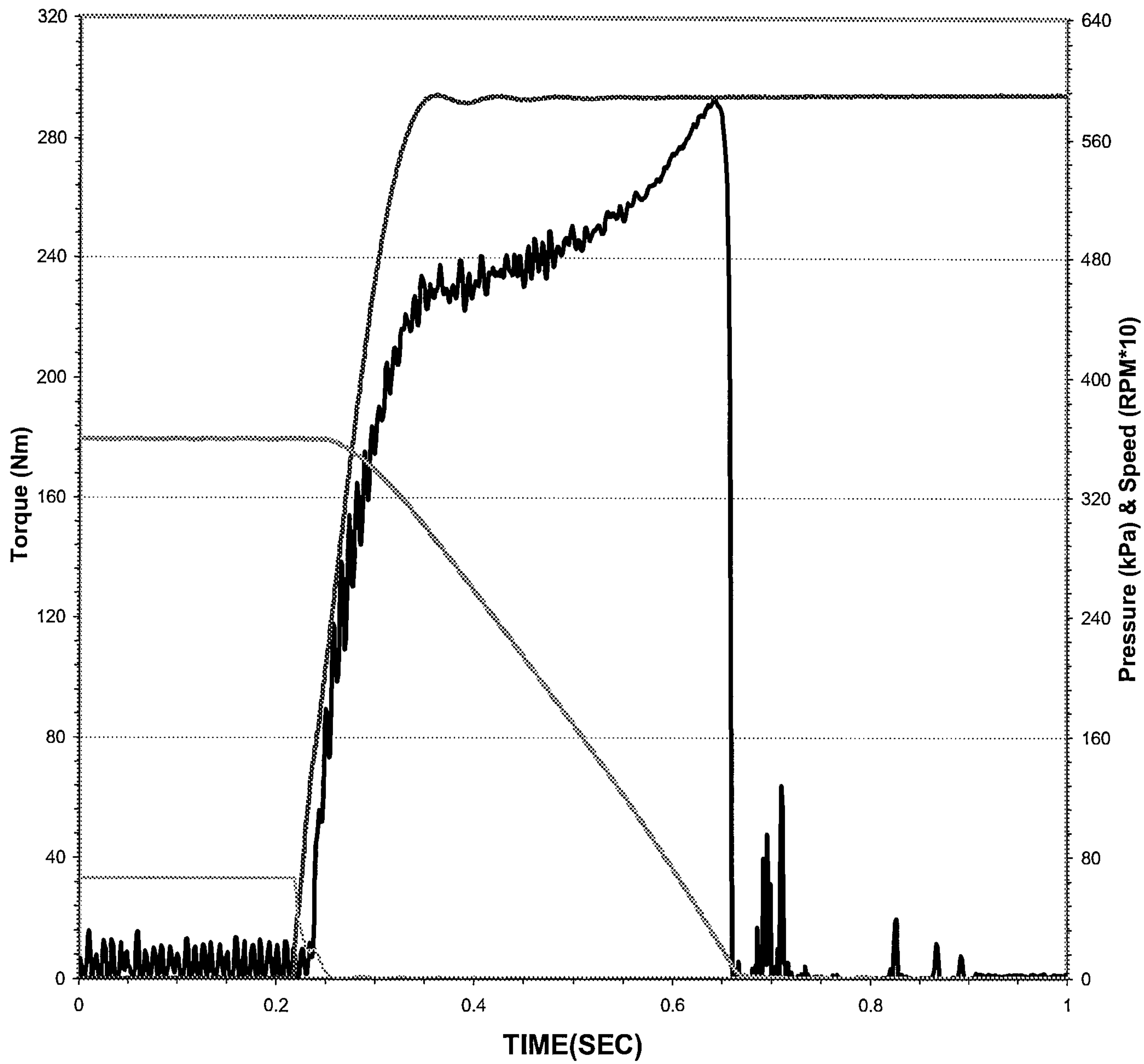
0.2 Sec Dyn:	**237 N*m**
Midpoint Dyn:	**238 N*m**
LwSpd Dynamic:	**270 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.115**
Midpoint Dyn:	**0.116**
LwSpd Dynamic:	**0.132**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/26/2010
Time of Test:	0:02:56
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	5001
Temperature:	86.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	587 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.442 Sec

Torque

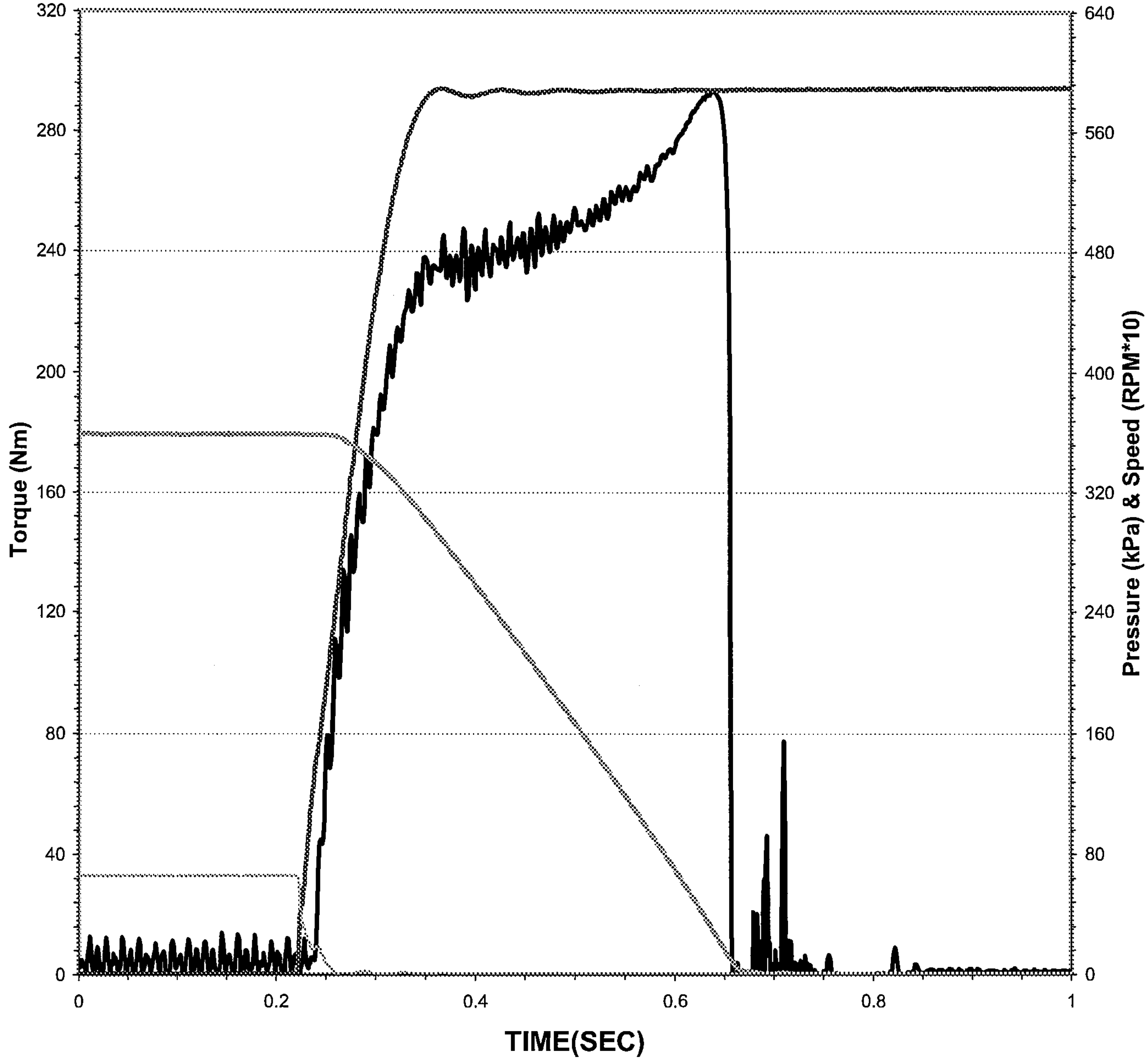
0.2 Sec Dyn:	233 N*m
Midpoint Dyn:	236 N*m
LwSpd Dynamic:	264 N*m

Coefficient of Friction

.2 Sec Dyn:	0.114
Midpoint Dyn:	0.115
LwSpd Dynamic:	0.129

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/26/2010
Time of Test:	10:27:26
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	7499
Temperature:	92.6 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	586 kPa
	(586 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.6 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.436 Sec

Torque

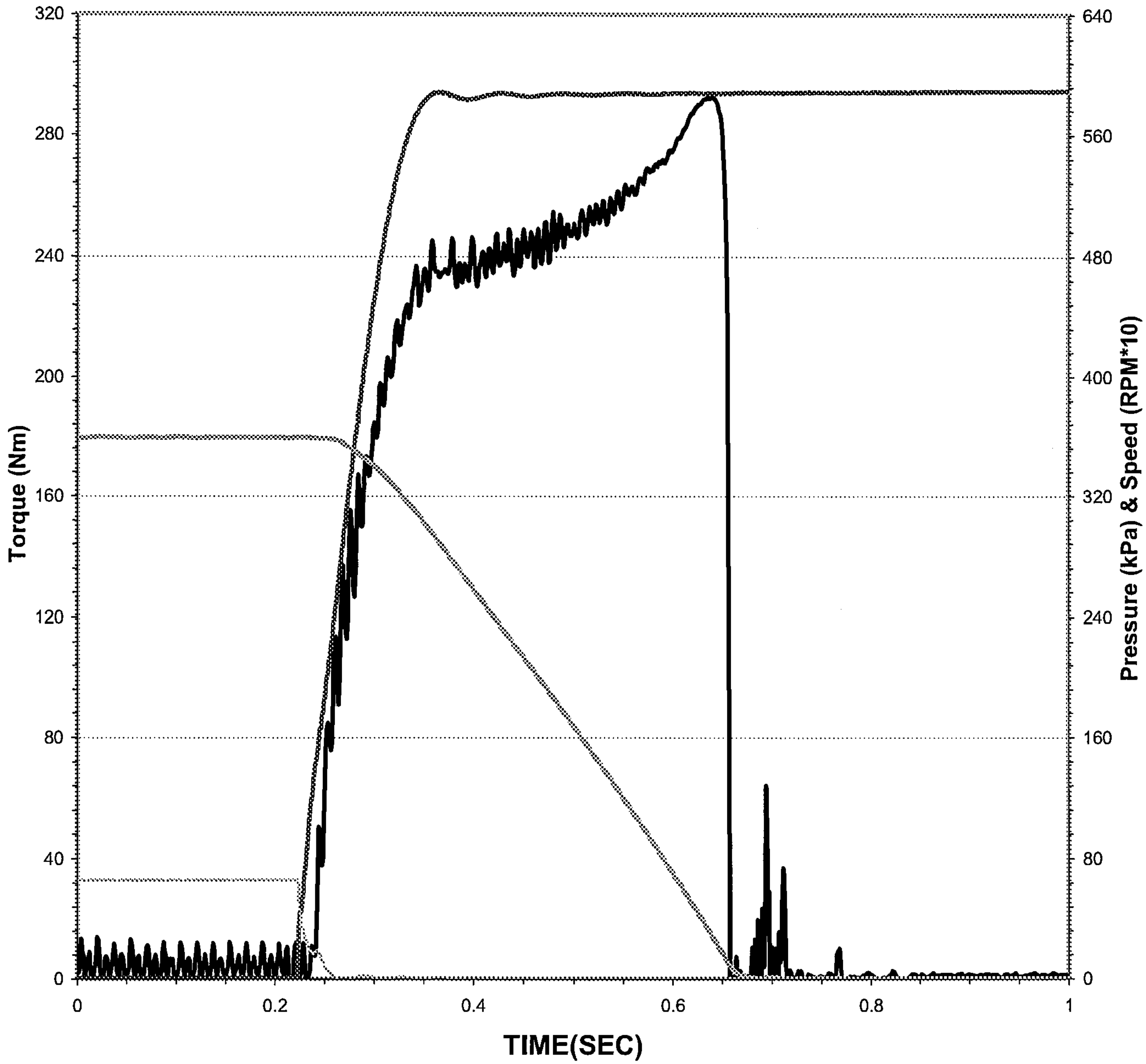
0.2 Sec Dyn:	238 N*m
Midpoint Dyn:	239 N*m
LwSpd Dynamic:	269 N*m

Coefficient of Friction

.2 Sec Dyn:	0.116
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.131

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/26/2010
Time of Test:	10:27:41
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	7500
Temperature:	92.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.435 Sec

Torque

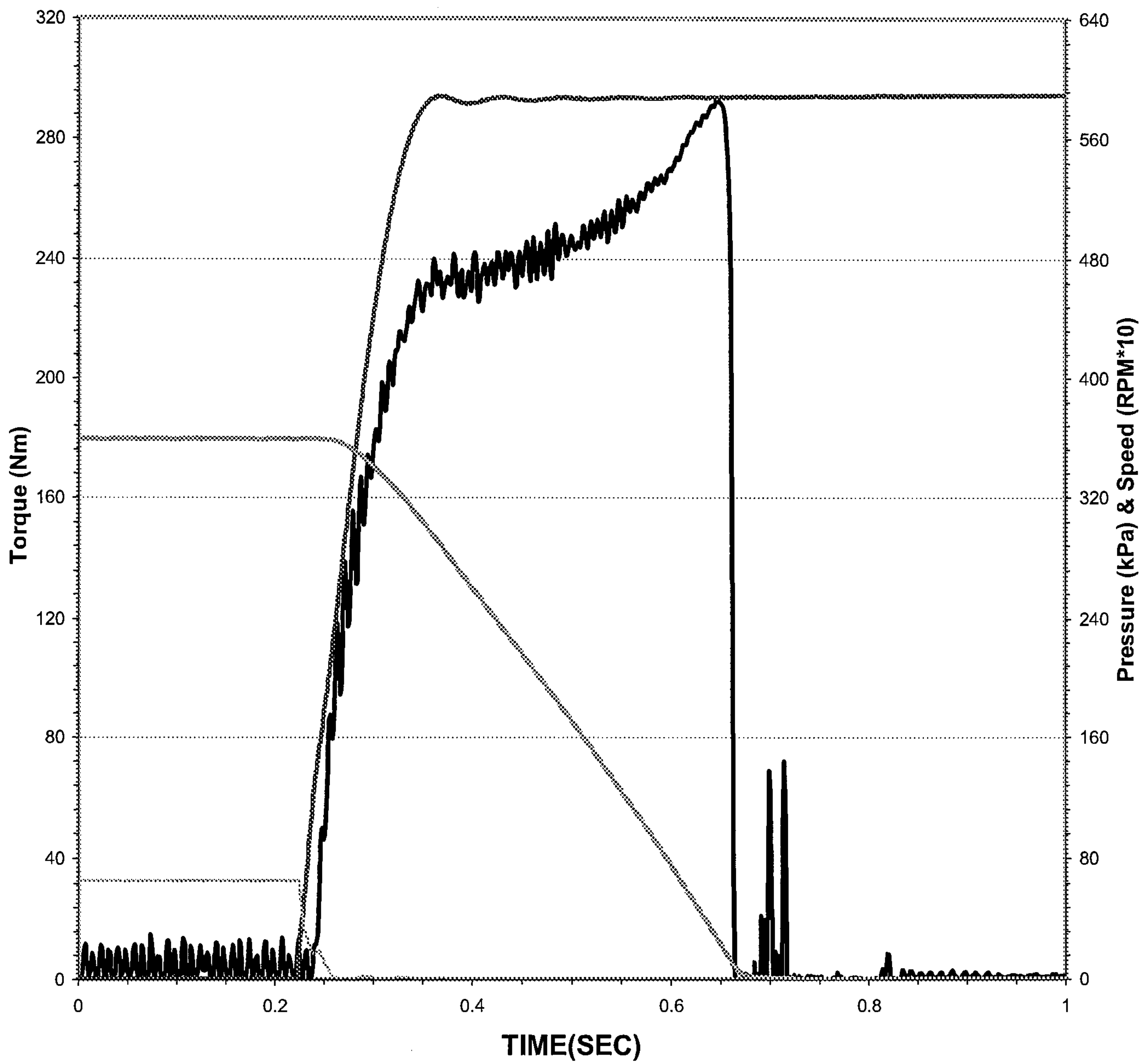
0.2 Sec Dyn:	239 N*m
Midpoint Dyn:	240 N*m
LwSpd Dynamic:	267 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.117
LwSpd Dynamic:	0.130

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/26/2010
Time of Test:	10:28:12
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	7501
Temperature:	86.3 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.439 Sec

Torque

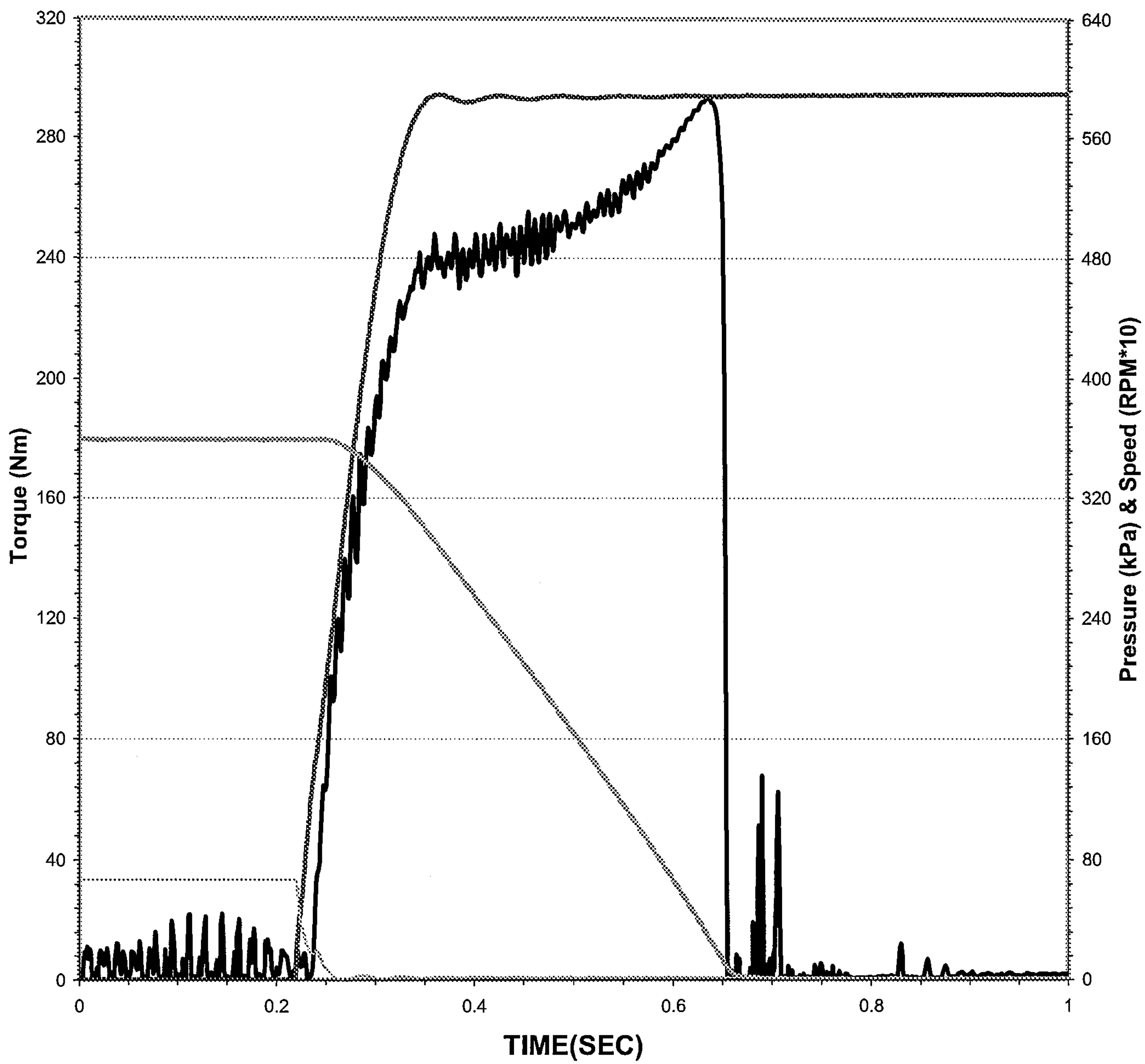
0.2 Sec Dyn:	237 N*m
Midpoint Dyn:	237 N*m
LwSpd Dynamic:	274 N*m

Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.134

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/26/2010
Time of Test:	20:52:28
Test Number:	C2-8-1553
Fluid Code:	LO254054
Cycle Number:	9998
Temperature:	93.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	586 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.435 Sec

Torque

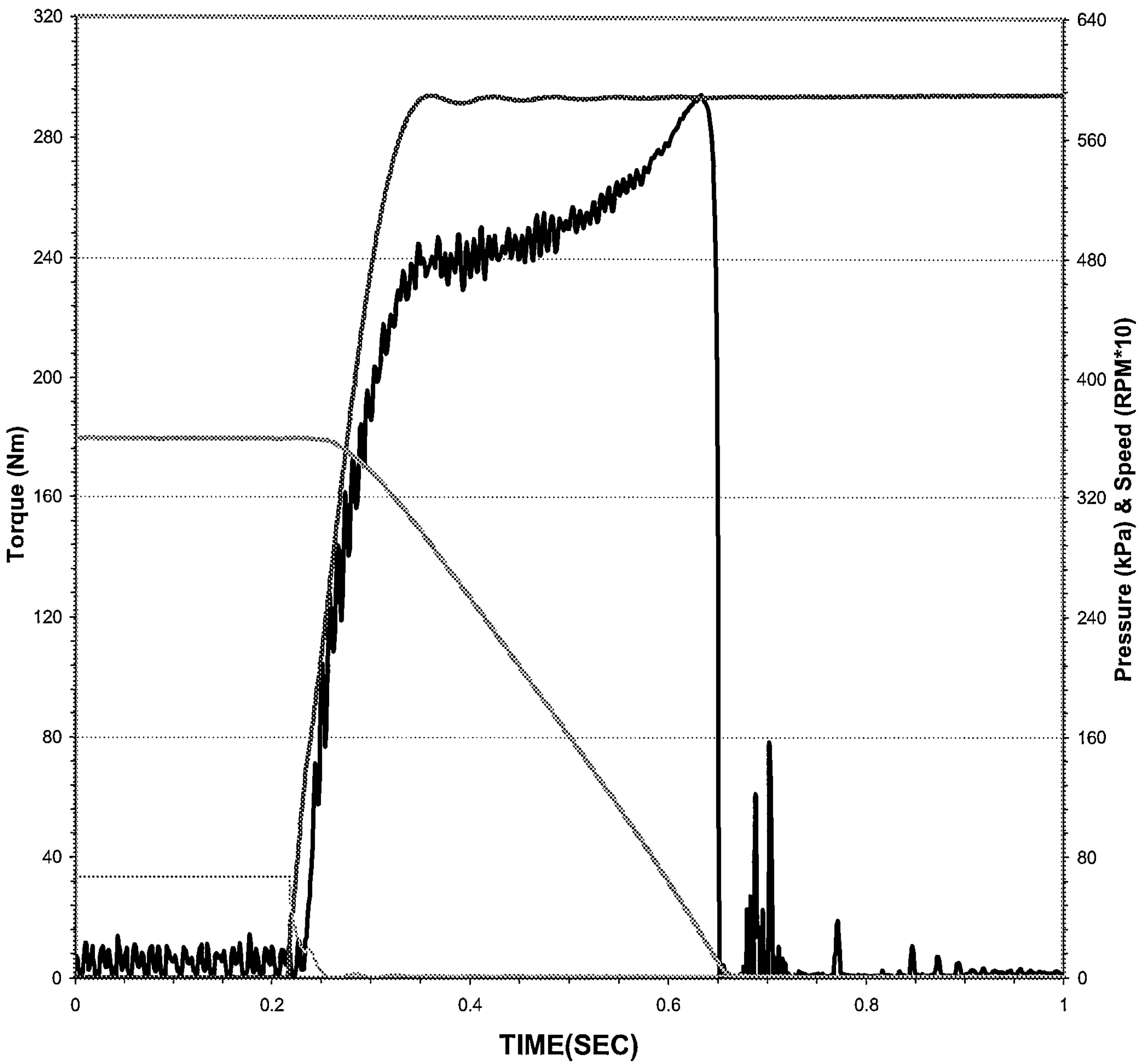
0.2 Sec Dyn:	241 N*m
Midpoint Dyn:	242 N*m
LwSpd Dynamic:	263 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.118
LwSpd Dynamic:	0.128

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/26/2010

Time of Test: 20:52:43

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 9999

Temperature: 92.9 °C
(93.3 ± 3.0 °C)

Apply Pressure: 586 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.7 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.435 Sec

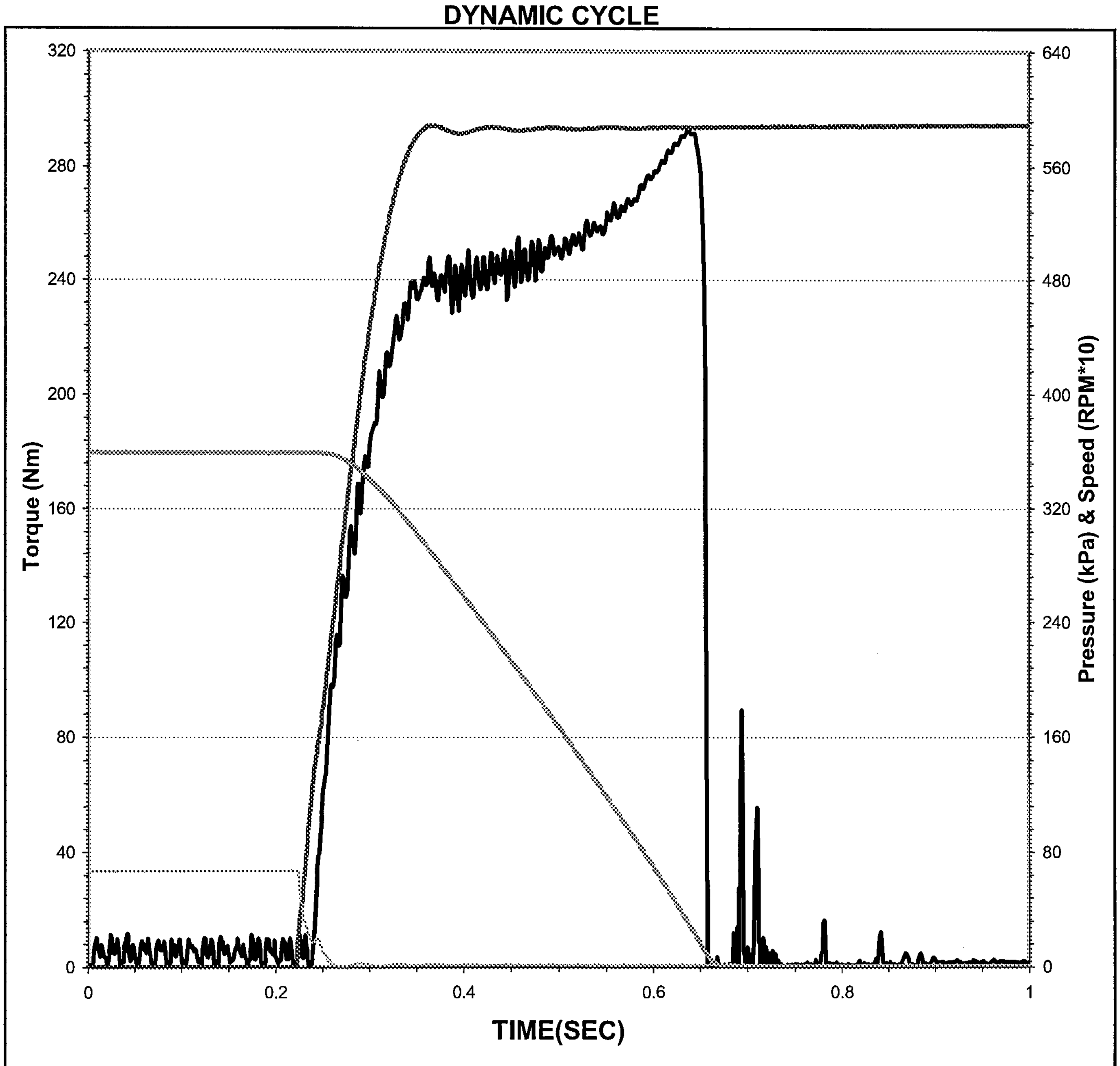
Torque

0.2 Sec Dyn:	**241 N*m**
Midpoint Dyn:	**241 N*m**
LwSpd Dynamic:	**263 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.117**
Midpoint Dyn:	**0.118**
LwSpd Dynamic:	**0.128**

ALLISON C-4 PAPER DATA



Date of Test: 7/26/2010

Time of Test: 20:52:58

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 10000

Temperature: 92.7 °C
(93.3 ± 3.0 °C)

Apply Pressure: 586 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.7 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.434 Sec

Torque

0.2 Sec Dyn:	241 N*m
Midpoint Dyn:	242 N*m
LwSpd Dynamic:	272 N*m

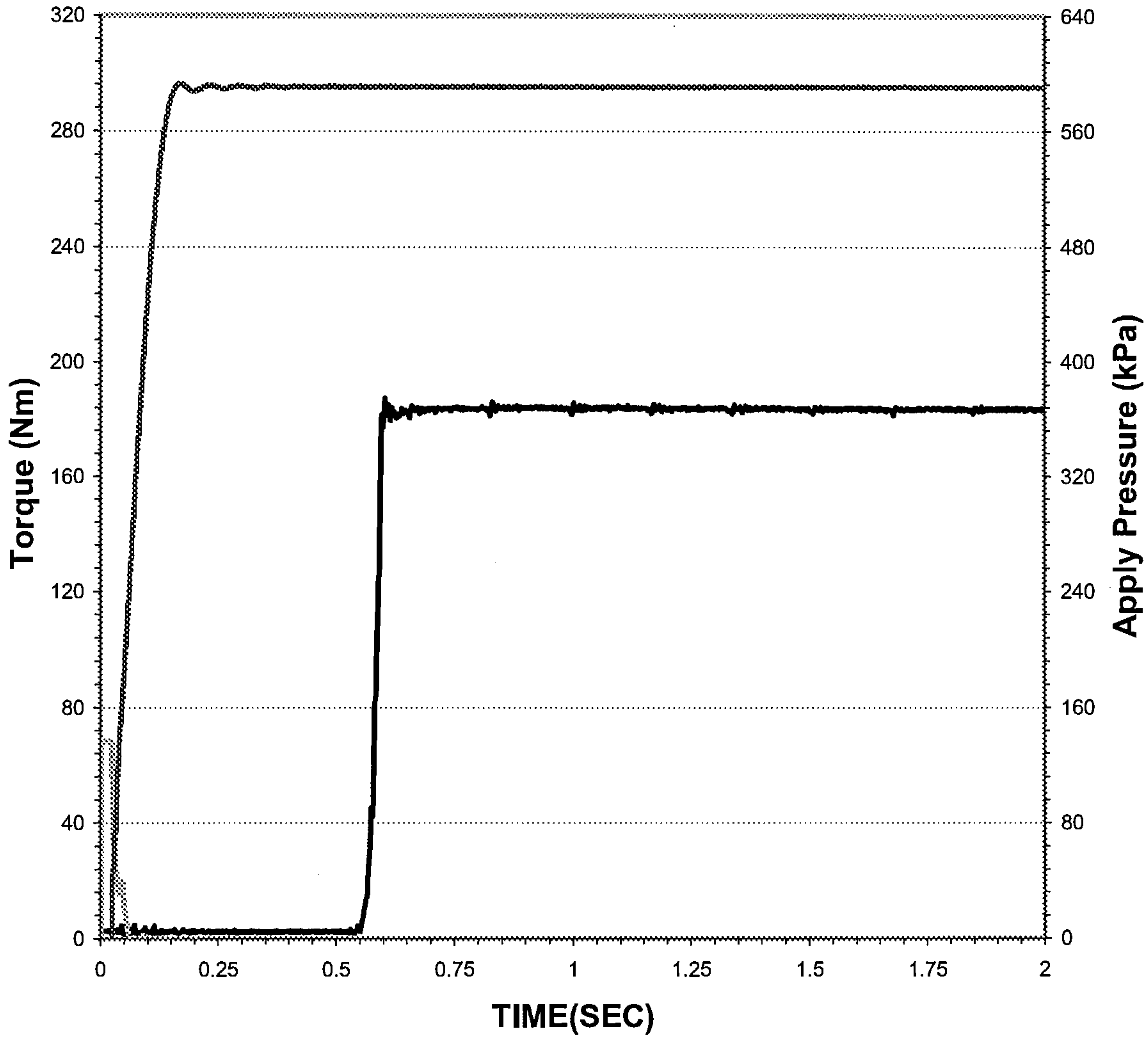
Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.118
LwSpd Dynamic:	0.132

STATIC TRACES

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/25/2010

Time of Test: 3:13:50

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 10

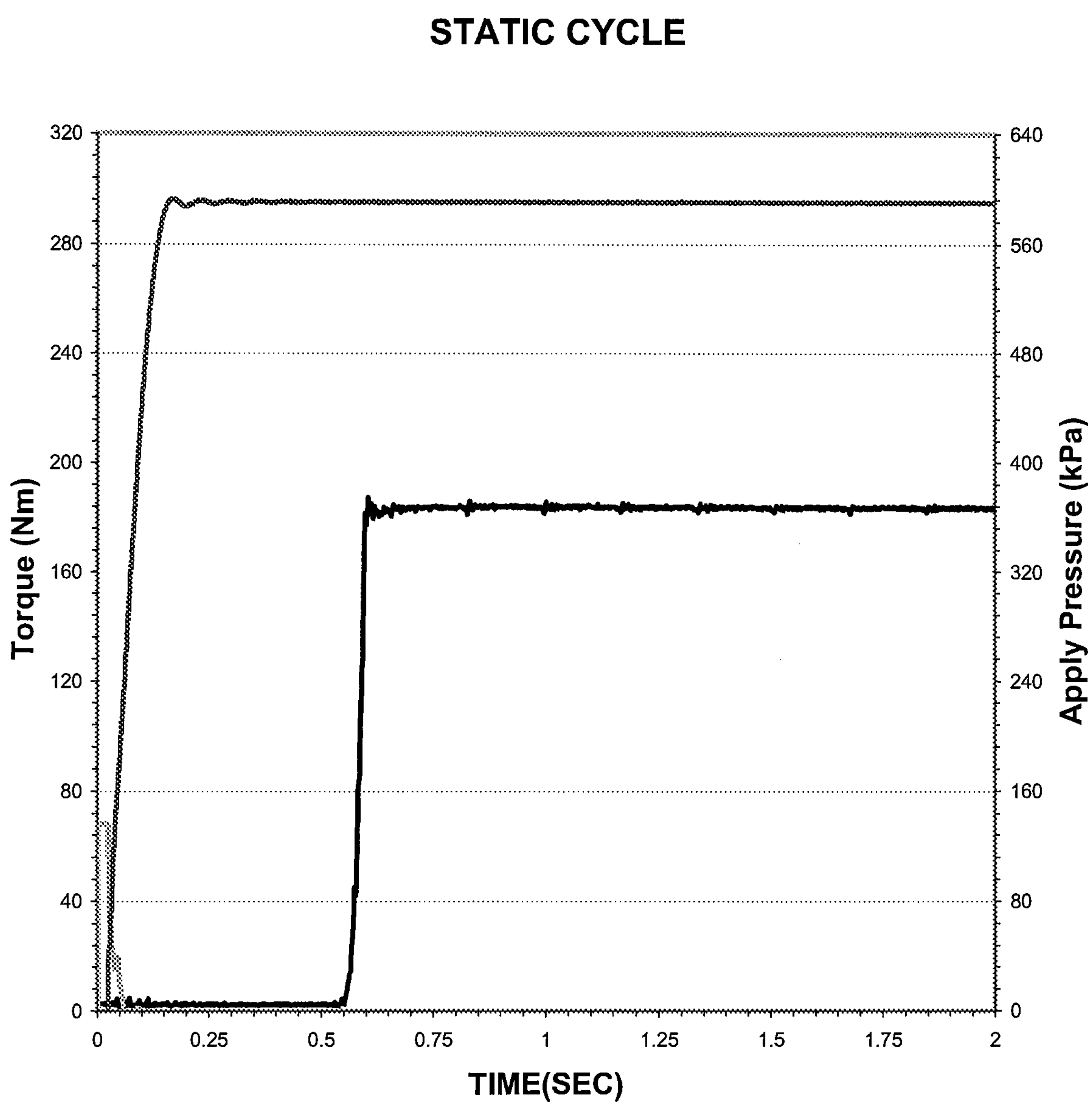
STATIC CYCLE

Apply Pressure:
At .25 Second: 591 kPa

Torque
Static Peak: 302 Nm
.25 Second: 280 Nm

Coefficient of Friction
Static Peak: 0.147
.25 Second: 0.136

ALLISON C-4 PAPER DATA



Date of Test: 7/25/2010

Time of Test: 3:36:36

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 100

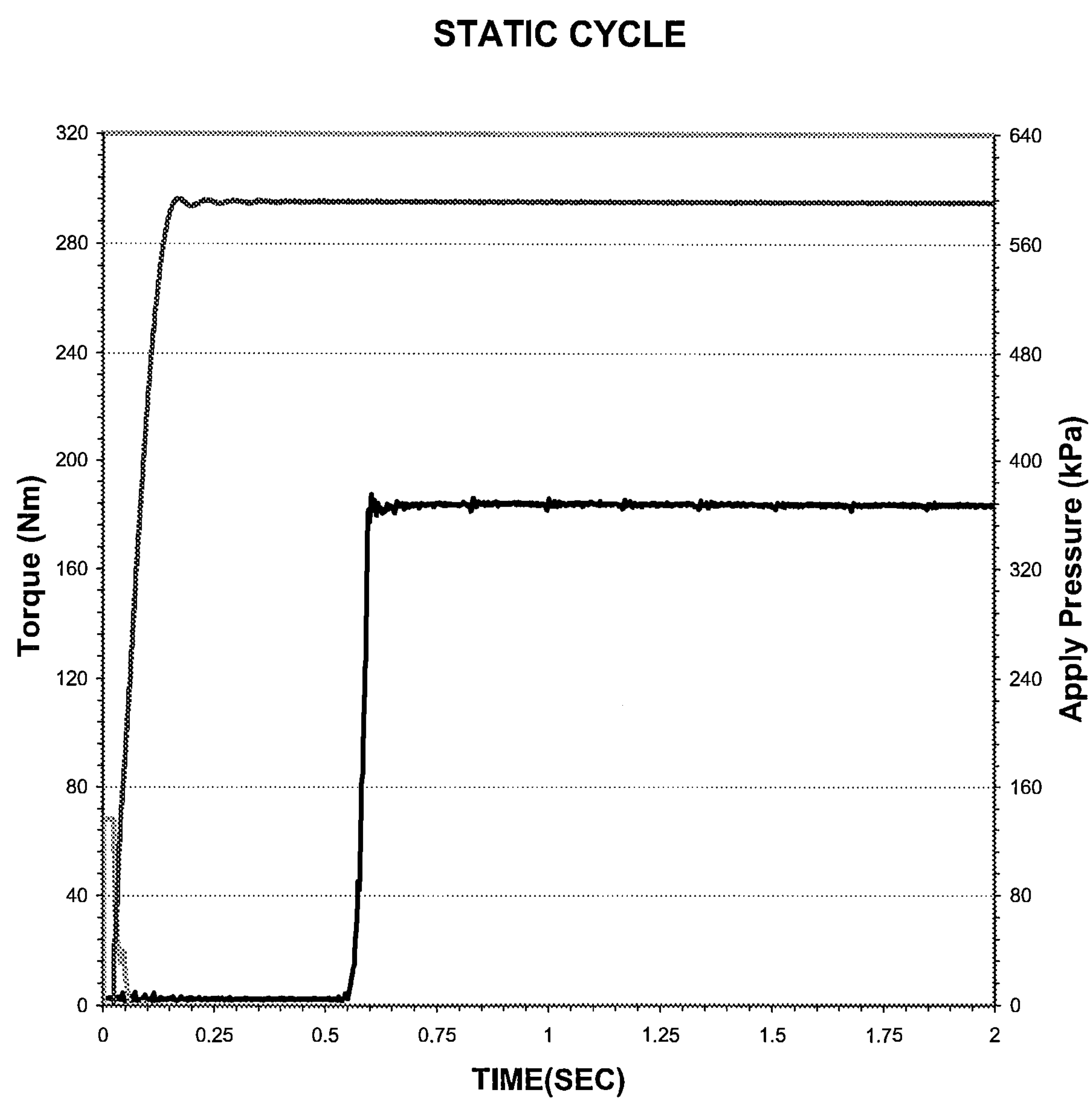
STATIC CYCLE

Apply Pressure:
At .25 Second: 592 kPa

Torque
Static Peak: 279 Nm
.25 Second: 270 Nm

Coefficient of Friction
Static Peak: 0.136
.25 Second: 0.131

ALLISON C-4 PAPER DATA



Date of Test: 7/25/2010

Time of Test: 5:16:52

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 500

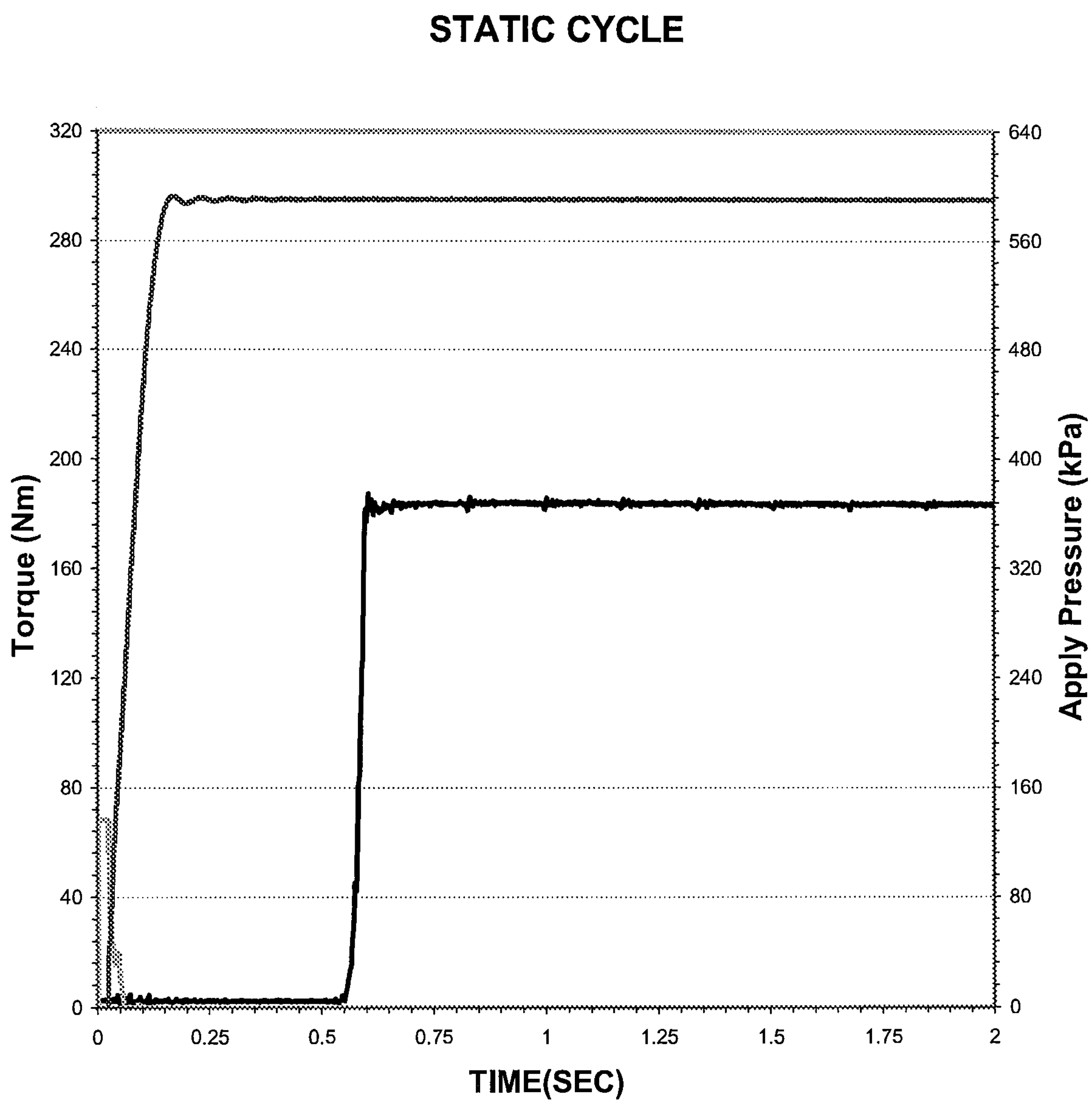
STATIC CYCLE

Apply Pressure:
At .25 Second: 587 kPa

Torque
Static Peak: 274 Nm
.25 Second: 269 Nm

Coefficient of Friction
Static Peak: 0.133
.25 Second: 0.131

ALLISON C-4 PAPER DATA



Date of Test: 7/25/2010

Time of Test: 7:22:08

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 1000

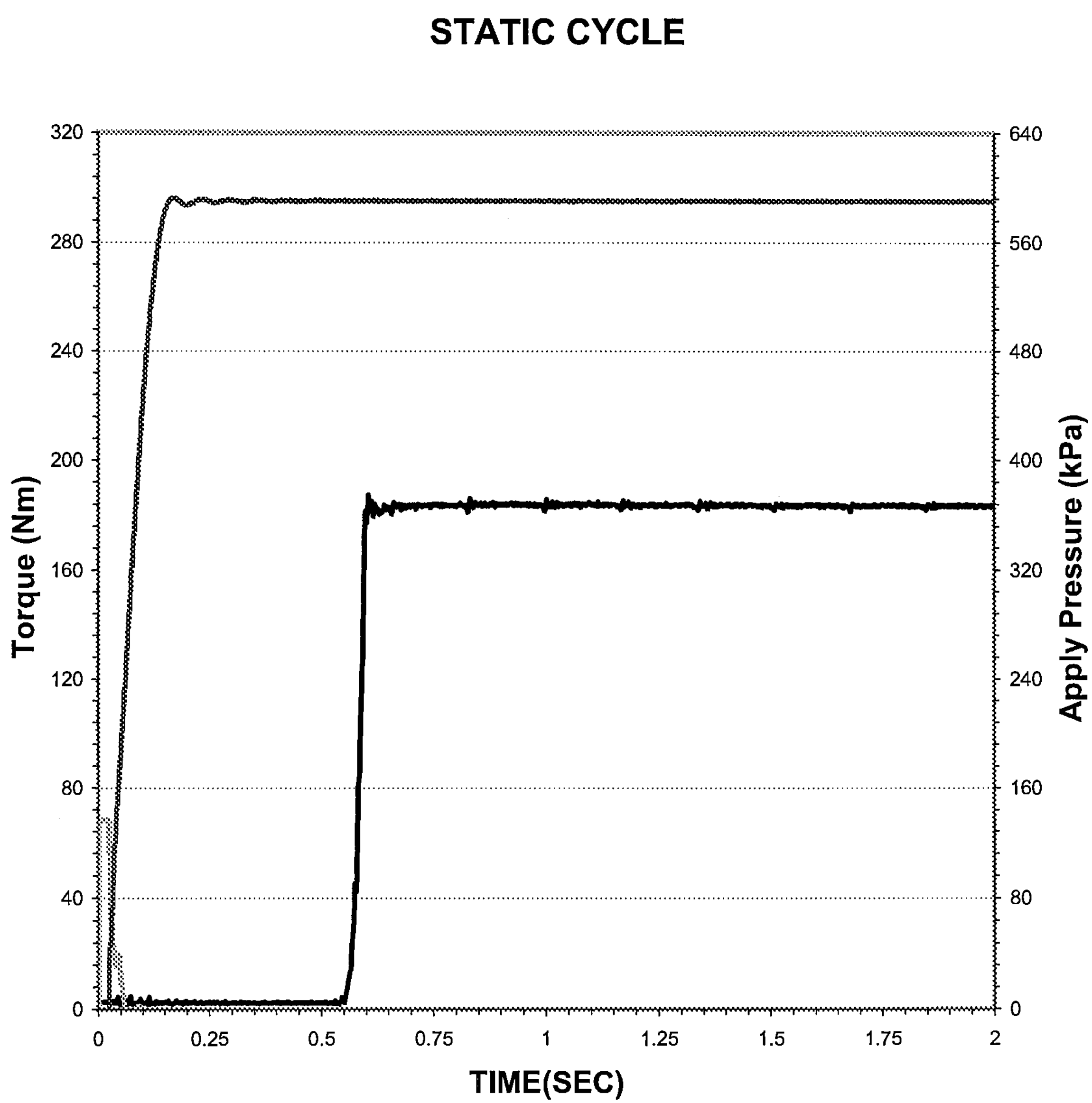
STATIC CYCLE

Apply Pressure:
At .25 Second: 587 kPa

Torque
Static Peak: 278 Nm
.25 Second: 273 Nm

Coefficient of Friction
Static Peak: 0.135
.25 Second: 0.133

ALLISON C-4 PAPER DATA



Date of Test: 7/25/2010

Time of Test: 13:37:25

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 2500

STATIC CYCLE

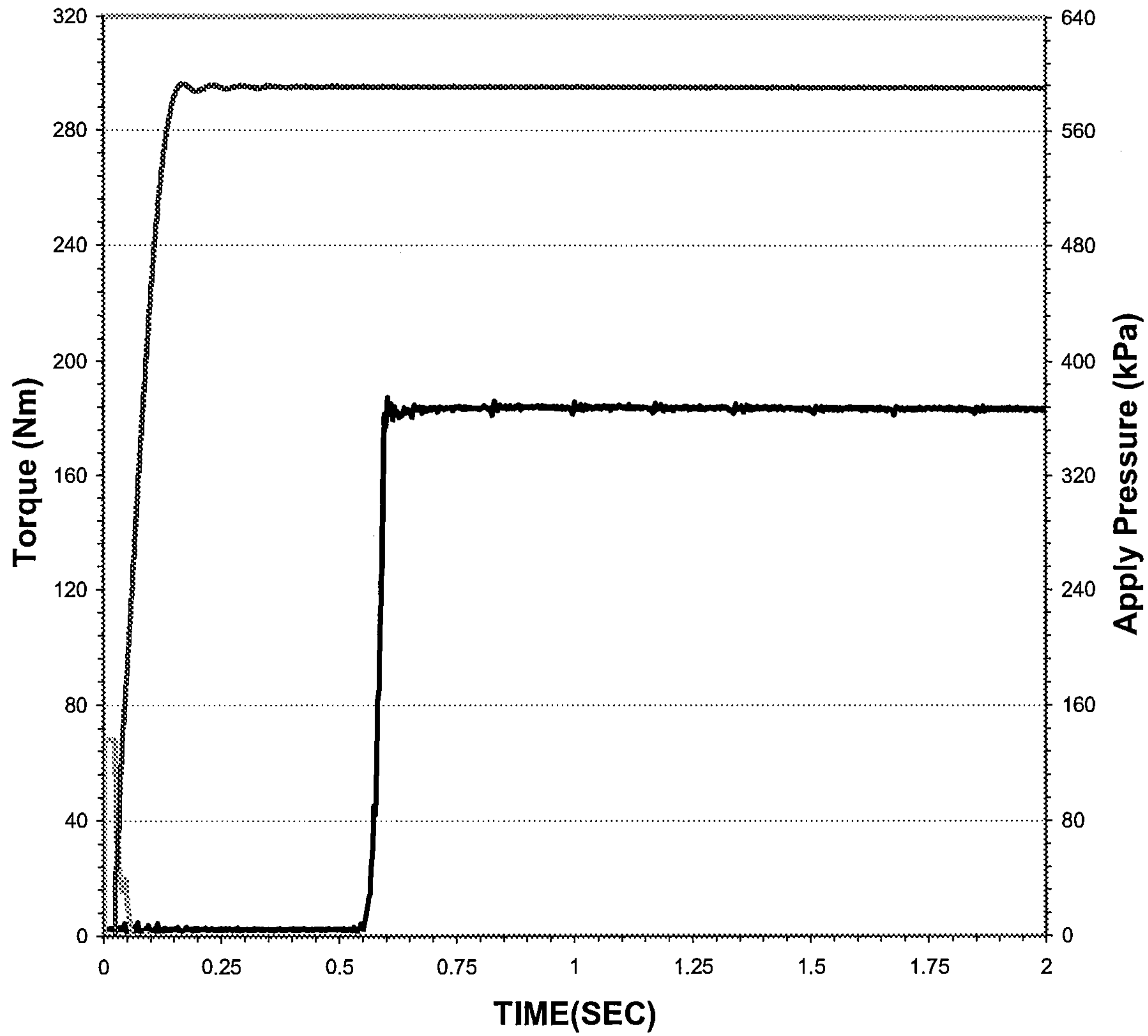
Apply Pressure:
At .25 Second: 586 kPa

Torque
Static Peak: 278 Nm
.25 Second: 269 Nm

Coefficient of Friction
Static Peak: 0.136
.25 Second: 0.131

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/26/2010

Time of Test: 0:02:41

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 5000

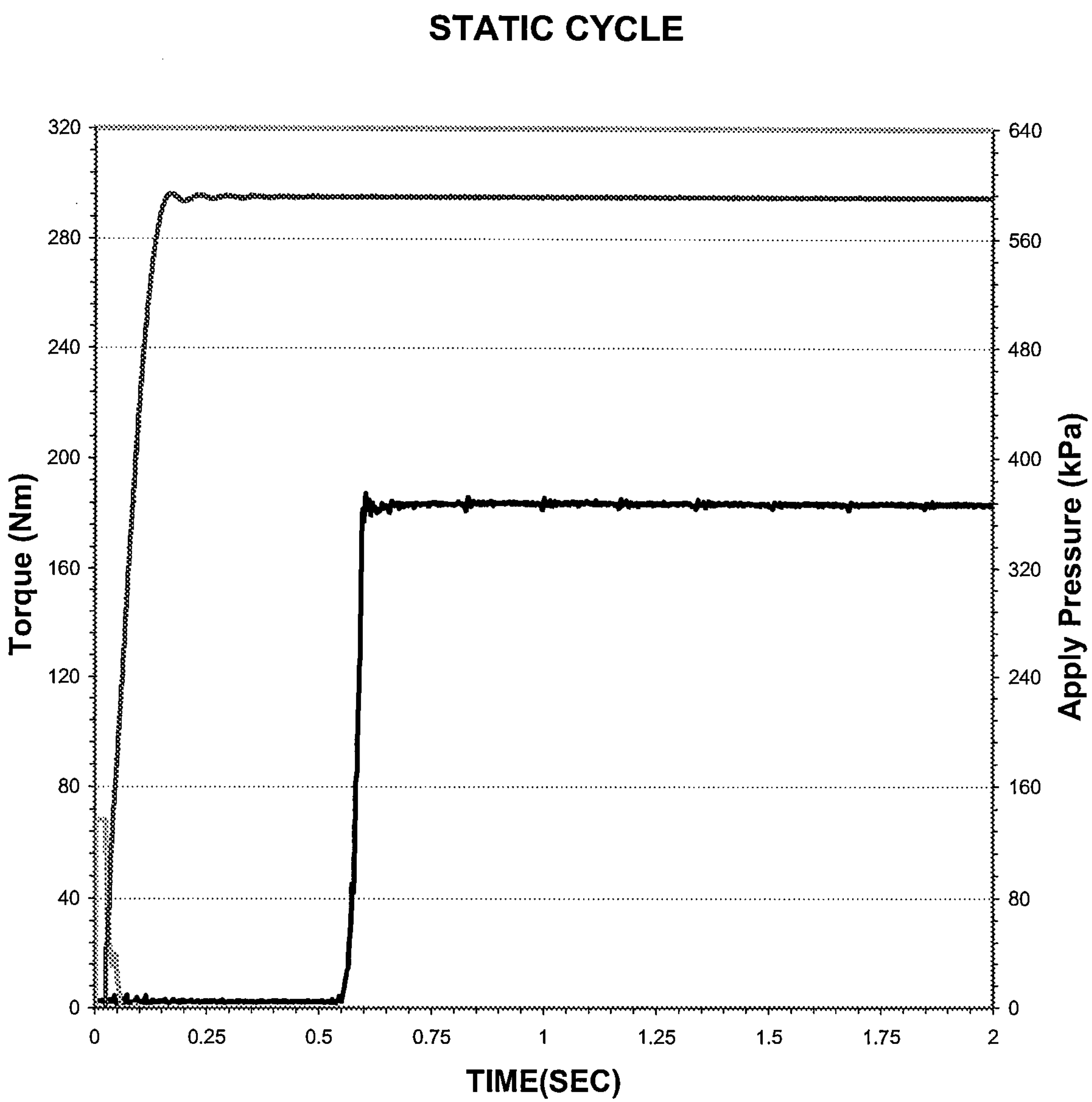
STATIC CYCLE

Apply Pressure:
At .25 Second: 586 kPa

Torque
Static Peak: 280 Nm
.25 Second: 274 Nm

Coefficient of Friction
Static Peak: 0.136
.25 Second: 0.133

ALLISON C-4 PAPER DATA



Date of Test: 7/26/2010

Time of Test: 10:27:57

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 7500

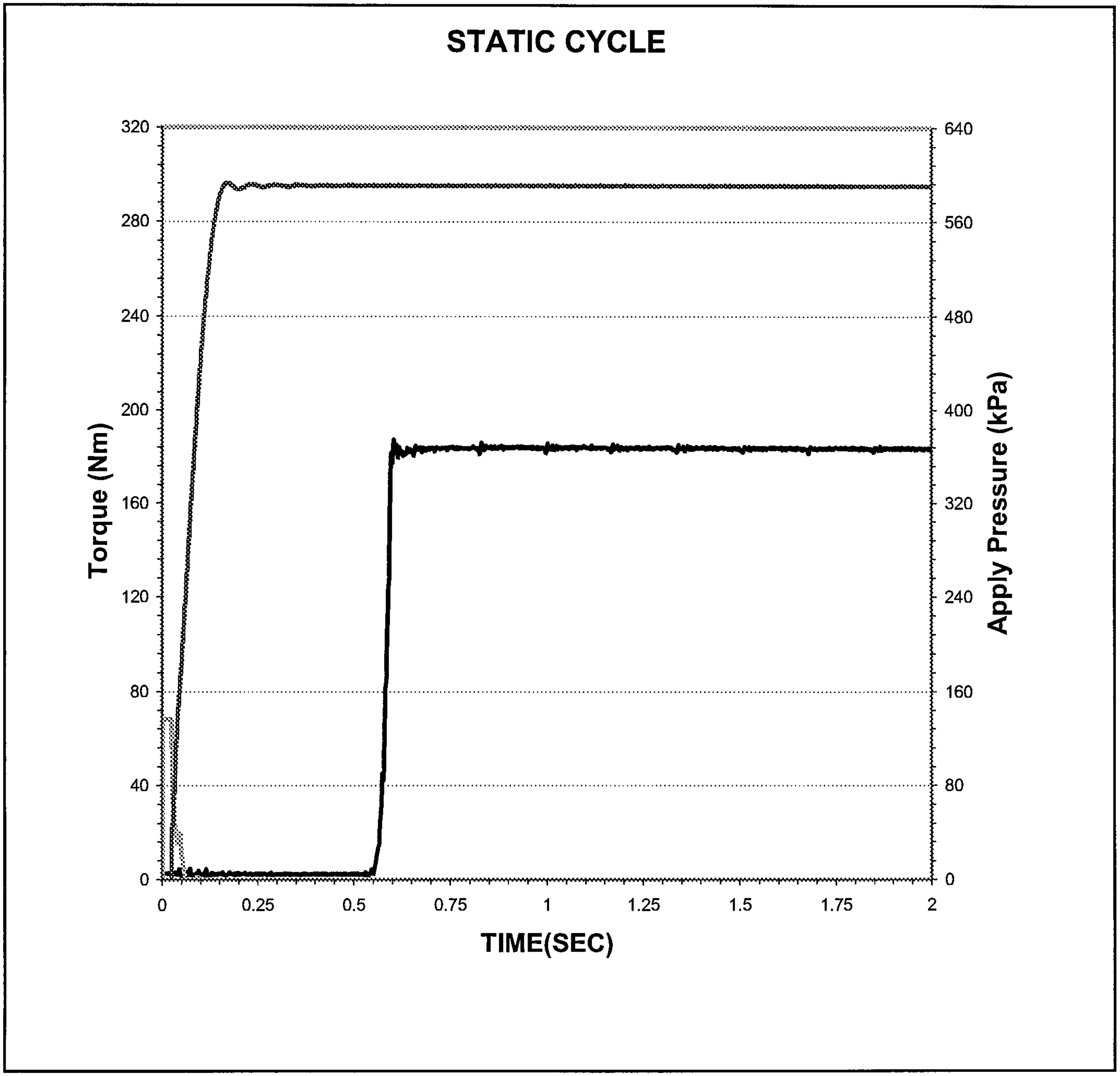
STATIC CYCLE

Apply Pressure:
At .25 Second: 586 kPa

Torque
Static Peak: 282 Nm
.25 Second: 274 Nm

Coefficient of Friction
Static Peak: 0.137
.25 Second: 0.134

ALLISON C-4 PAPER DATA



Date of Test: 7/26/2010

Time of Test: 20:53:14

Test Number: C2-8-1553

Fluid Code: LO254054

Cycle Number: 10000

STATIC CYCLE

Apply Pressure:
At .25 Second: 586 kPa

Torque
Static Peak: 285 Nm
.25 Second: 277 Nm

Coefficient of Friction
Static Peak: 0.139
.25 Second: 0.135

C4 SEAL TEST SUMMARY SHEET

Test Sponsor: SOUTHWEST RESEARCH INSTITUTE

Oil Code: 254054
Secondary Code:
Test Key:
SwRI Code: 488557
Date: 20101206

Elastomer	Candidate			Average	MILPRF2104G Batch 12-06	Limits
V1 A-7-0060-85-ETI						
Volume Change, %	6.97	7.14	7.07	7.06	14.16	0.00 to 20.00
Hardness Change, pts.	-1	-2	-2	-2	-7	-15 to 0
V2 P-250						
Volume Change, %	4.81	5.63	5.48	5.31	8.30	0.00 to 12.00
Hardness Change, pts.	-1	-1	-2	-1	-3	-7 to 3
V3 FM-L-69						
Volume Change, %	7.25	7.53	7.65	7.48	14.80	0.00 to 22.00
Hardness Change, pts.	-3	-2	-3	-3	-8	-14 to 0
P1 A-6-0160-85-ETI						
Volume Change, %	2.21	2.37	2.31	2.30	4.07	0.00 to 8.00
Hardness Change, pts.	-2	-2	-2	-2	-2	-10 to 0
P2 GR-A2256						
Volume Change, %	3.64	3.64	3.53	3.60	6.61	0.00 to 8.00
Hardness Change, pts.	-3	-4	-4	-4	-3	-11 to 3
P3 6830						
Volume Change, %	0.22	-0.07	0.13	0.10	2.09	0.00 to 4.00
Hardness Change, pts.	1	0	0	0	-1	-8 to 4
F1 7V2127						
Volume Change, %	0.66	0.68	0.70	0.68	0.77	0.00 to 3.00
Hardness Change, pts.	-2	-1	-1	-1	0	-5 to 4
F2 V150						
Volume Change, %	0.84	0.83	0.77	0.81	1.14	0.00 to 4.00
Hardness Change, pts.	0	0	0	0	0	-2 to 5
N1 GR-N1386						
Volume Change, %	-3.42	-3.30	-3.02	-3.25	0.29	0.00 to 5.00
Hardness Change, pts.	1	1	2	1	4	-12 to 12
N2						
Volume Change, %						0.00 to 6.00
Hardness Change, pts.						-9 to 5

Charles Nyttom [signature]

for Mike Birke
Sr. Research Scientist
Petroleum Products Research Dept.

APPENDIX D3. – EVAULATION OF CANDIDATE LO25033 IN ALLISON C4 TRANSMISSION TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted For

ARMY LAB

Oil Code:
LO250033

Test Number:
C4-6-1284

July 20, 2010

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

VIII. Graphite Clutch Friction Test

Test Laboratory:	SWRI	Lab Fluid Code:	LO-250033
Test Number:	C4-6-1284	Sponsor Fluid Code:	LO250033
Friction Plate Batch:	BATCH 44	Completion Date:	7/20/2010
Steel Plate Batch:	10/9/2008		

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0010	0.0001
Clutch Plate	0.0620	0.0523

	Before	After
Pack Clearance	0.4318	0.5334

Reference Tests

Test Number	Test Date	Test Fluid
C4-0-1257	11/25/09	PASS REF-L-06-04
C4-0-1267	01/08/10	PASS REF-L-06-04
C4-0-1278	05/26/10	PASS REF-L-06-04

	New	EOT
Viscosity at 40°C, cSt	53.96	43.03
Viscosity at 100°C, cSt	10.03	8.28
Iron Content, ppm	2	70

D5185	New Fluid (ppm)
Ba	<1
B	69
Ca	780
Mg	1101
P	1111
Si	7
Na	8
Zn	1294

Name: Matt Jackson

Signature:

Title: Manager

Date: 7/26/10

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO250033**	Test Number:	**C4-6-1284**
Lab Fluid Code:	**250033**	Fric. Plate Batch:	**Batch 44**
Completion Date:	**7/20/2010**	Steel Plate Batch:	**10/9/2008**

PHASE A

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
500	1.26	47	69	36	33	90	70
1000	1.39	41	67	31	36	86	69

PHASE B

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (0.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
1500	0.80	99	142	83	59	161	153
2000	0.85	93	142	72	70	156	151
2500	0.87	93	135	68	67	158	150
3500	0.90	90	137	62	75	157	148
4000	0.90	91	136	60	76	154	148
4500	0.92	88	136	58	78	153	148
5000	0.90	91	134	60	74	154	147
5500	0.89	92	133	64	69	166	147

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.80	0.89	11.25	P
0.2 Second Dynamic Coeff.	N/A	N/A	0.078	0.060	-23.077	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.093	0.086	-7.527	F
Static Friction Coeff.	N/A	N/A	0.133	0.125	-6.015	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.151	0.156	3.311	
0.25 Second Low Speed Coeff.	N/A	N/A	0.143	0.138	-3.497	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-GRAPHITE FRICTION TEST

Candidate Fluid: LO250033 **Test Number : C4-6-1284** **Completion Date : 7/20/2010**

Lab Fluid Code : LO-250033 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 44**

(all units in mm)

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.2560	2.1940	2.2560	2.2060	0.0620		0.0500
	120	2.2580	2.2150	2.2590	2.2070	0.0430		0.0520
	240	2.2590	2.2030	2.2600	2.2090	0.0560		0.0510
	Average					0.0537	0.0523	0.0510
STEEL SEPARATORS								
1	Top	1.7530	1.7530	1.7530	1.7530	0.0000		0.0000
	120	1.7520	1.7520	1.7510	1.7510	0.0000		0.0000
	240	1.7550	1.7550	1.7550	1.7550	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7530	1.7520	1.7530	1.7530	0.0010		0.0000
	120	1.7560	1.7560	1.7550	1.7550	0.0000		0.0000
	240	1.7560	1.7560	1.7560	1.7560	0.0000		0.0000
	Average					0.0003	0.0002	0.0000

PLATE CONDITION AT E.O.T. PLATES IN GOOD CONDITION
(Anything Unusual)

Test Date: 7/20/2010

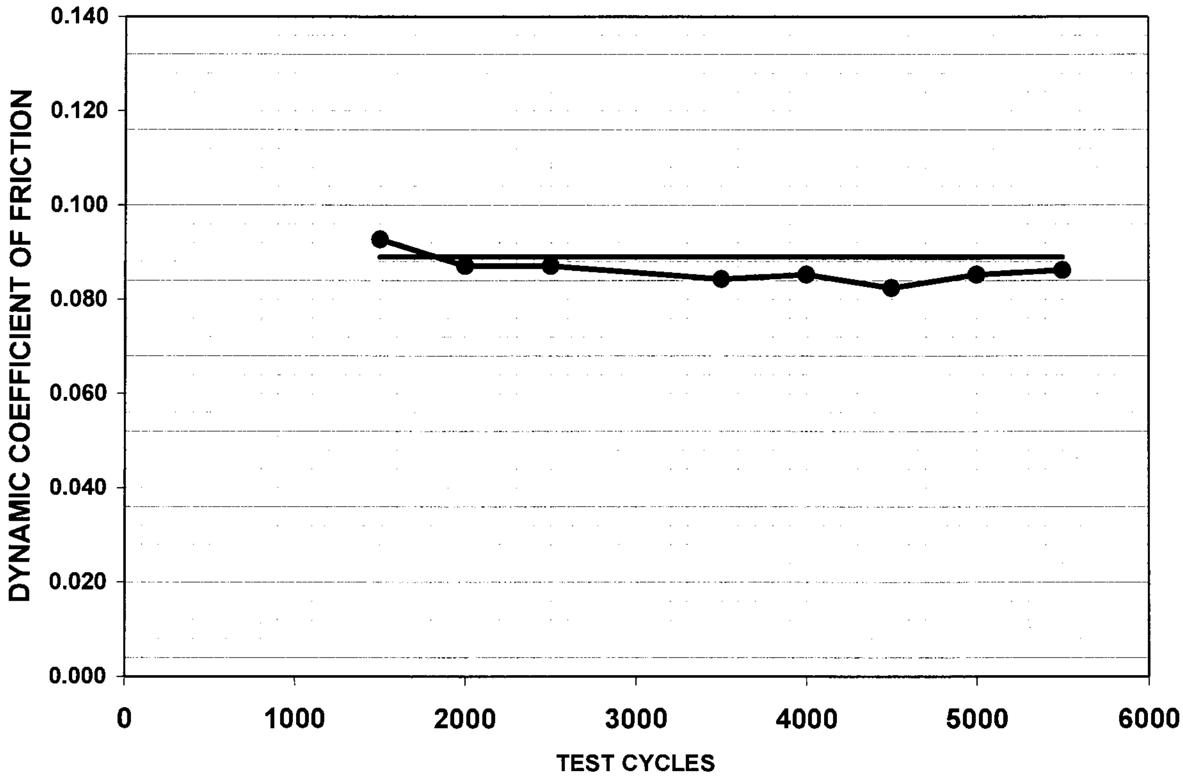
Operator's Name: JOE M

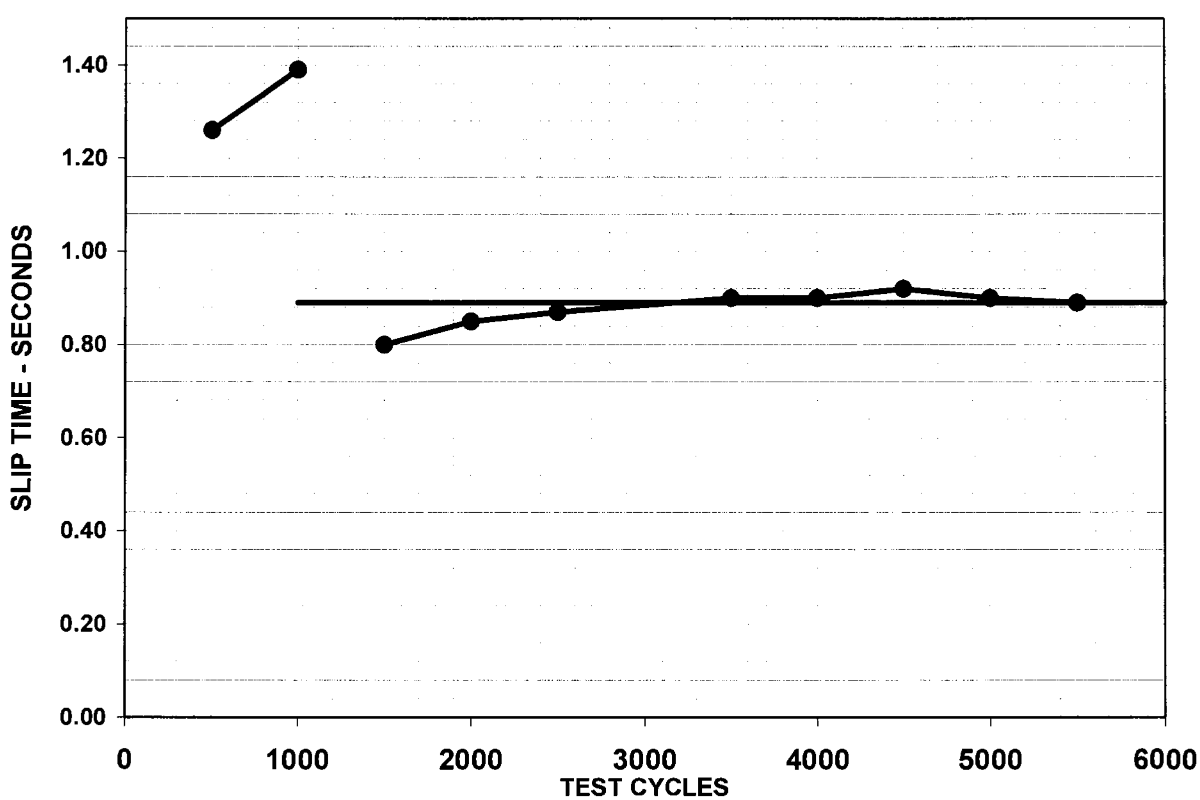
Reviewed By (Signature and Date)
7/28/10

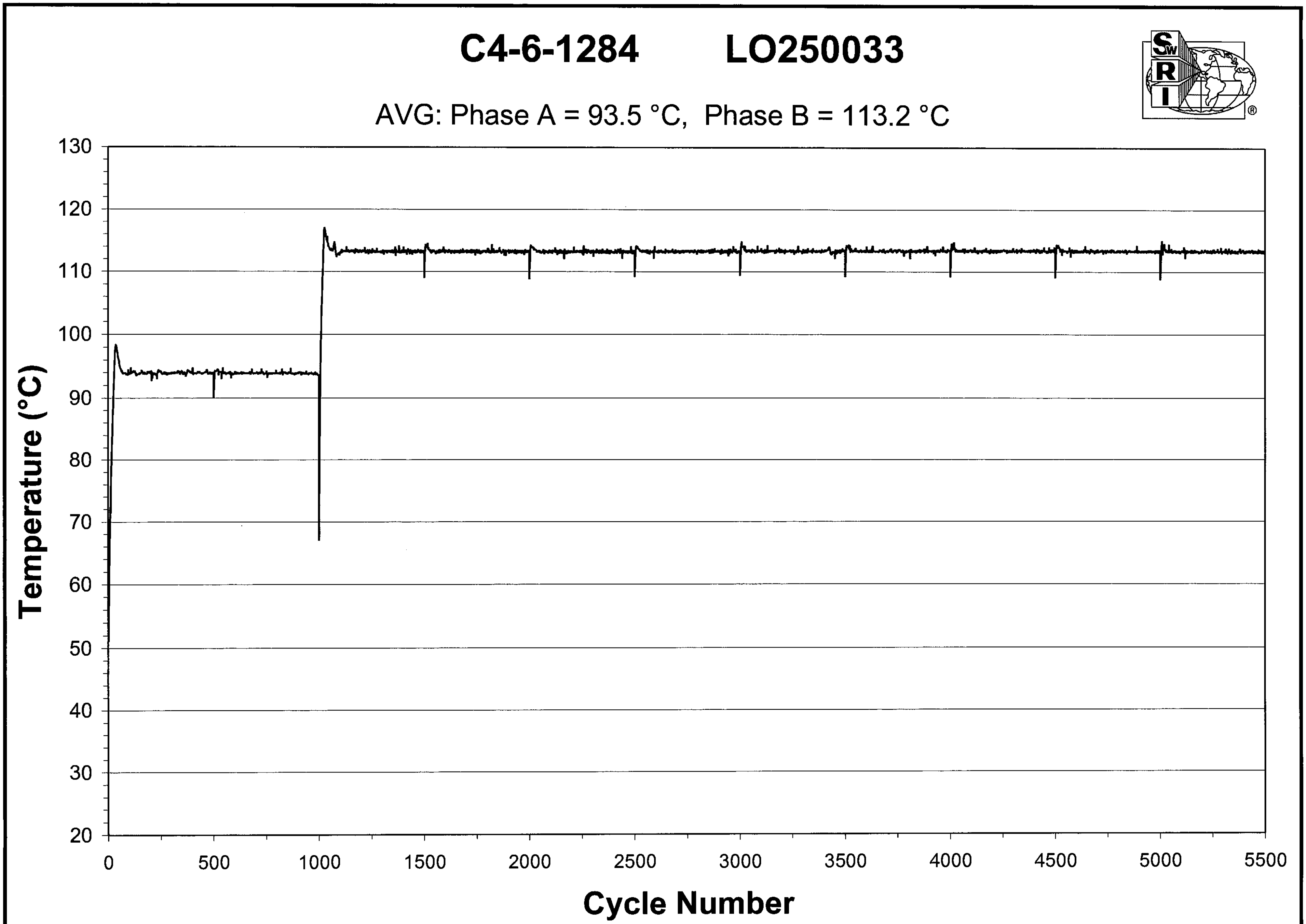
Pack ID#: 4417

EOT Date: 7/20/2010
Test Number: C4-6-1284

Fluid Code: LO250033
Plate Batch: Batch 44
Steel Batch: 10/9/2008



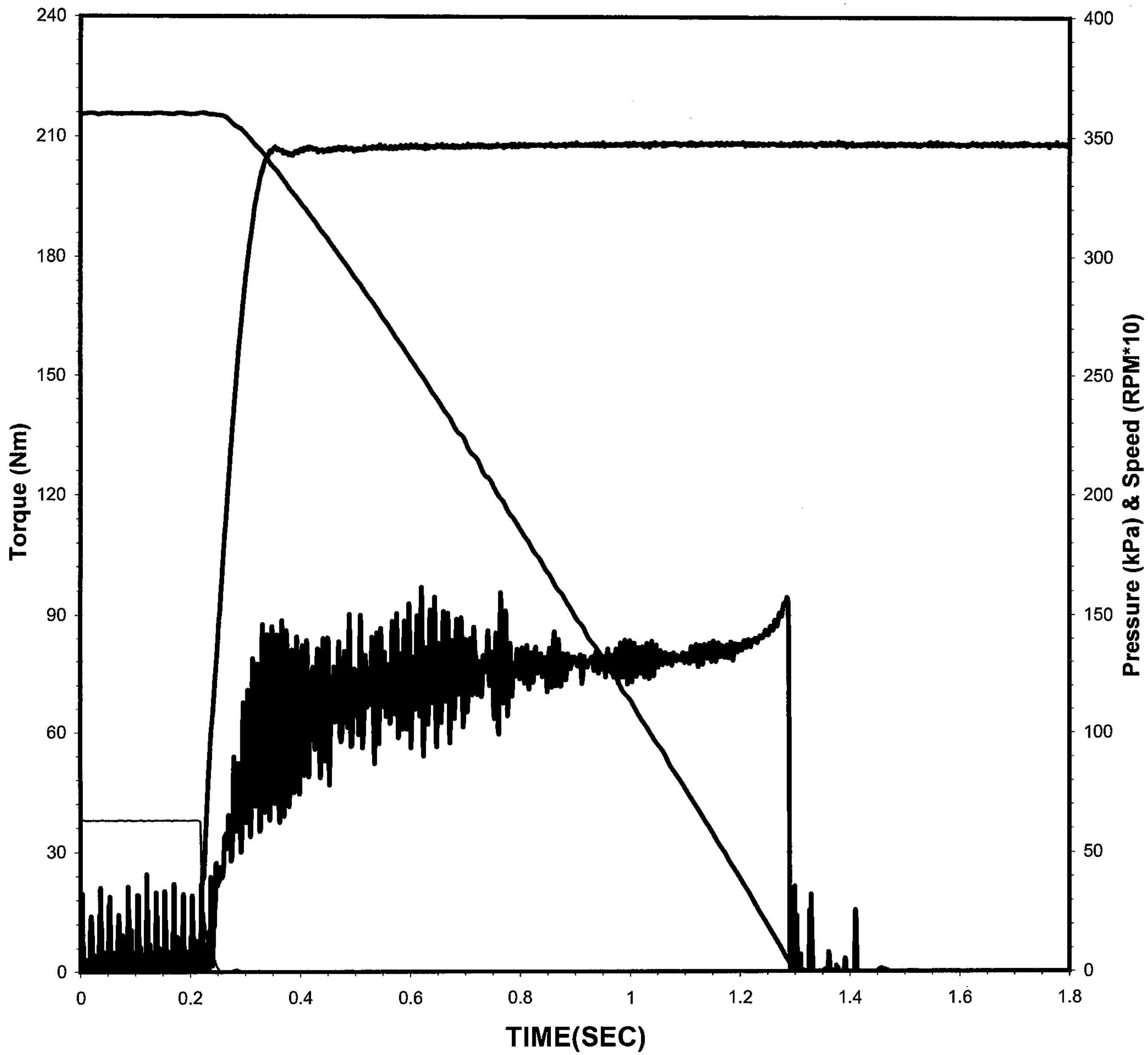



C4-6-1284 LO250033
AVG: Phase A = 93.5 °C, Phase B = 113.2 °C
Temperature (°C)
130
120
110
100
90
80
70
60
50
40
30
20
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Cycle Number

DYNAMIC TRACES

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/19/2010
Time of Test:	11:47:50
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	10
Temperature:	72.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	347 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.072 Sec

Torque

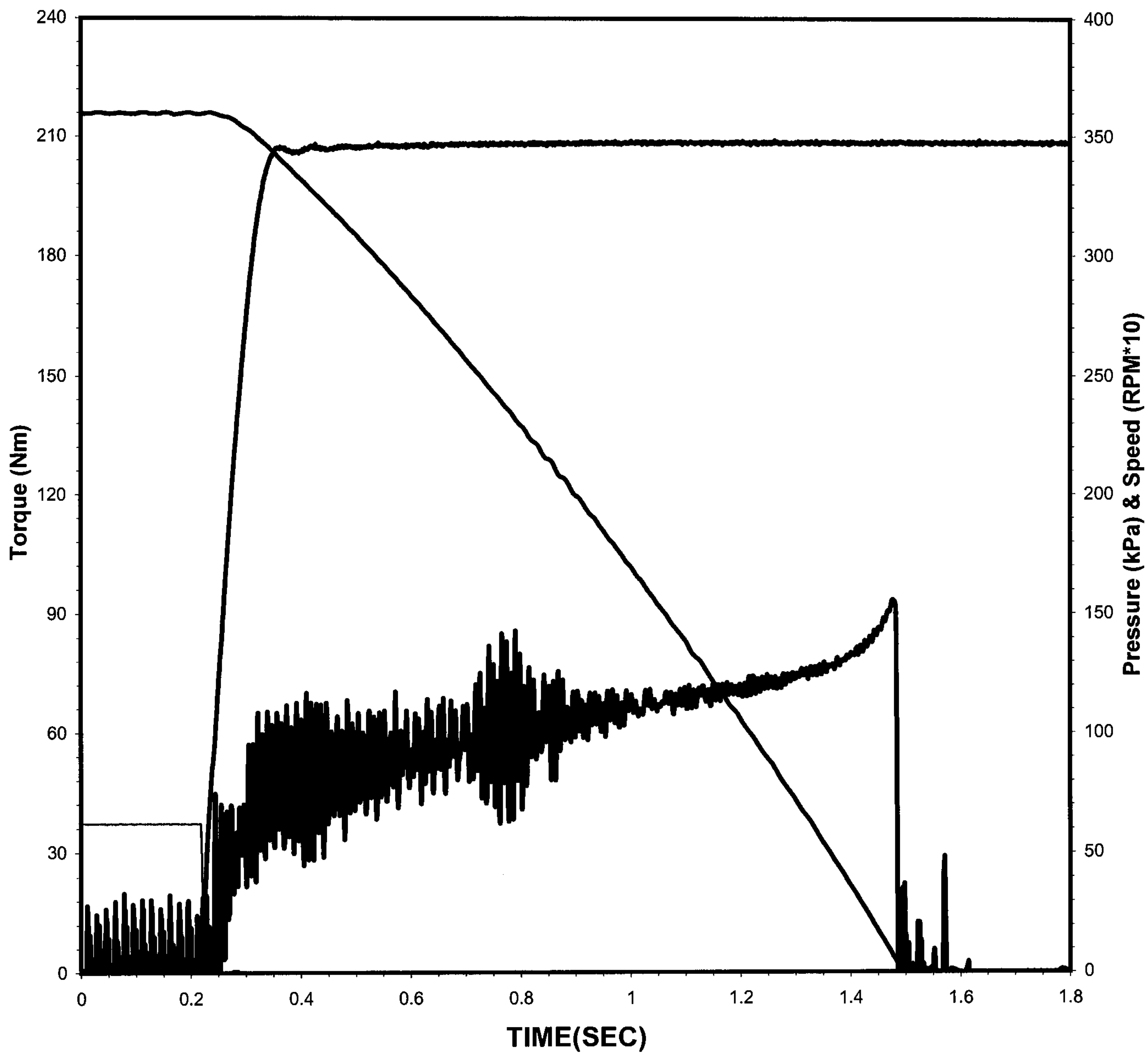
0.2 Sec Dyn:	64 N*m
Midpoint Dyn:	78 N*m
LwSpd Dynamic:	94 N*m

Coefficient of Friction

.2 Sec Dyn:	0.106
Midpoint Dyn:	0.129
LwSpd Dynamic:	0.156

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/19/2010

Time of Test: 13:50:17

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 499

Temperature: 93.8 °C
(93.3 ± 3.0 °C)

Apply Pressure: 349 kPa
(345 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 14.2 KJ
(14.50 ± 0.40 KJ)

Engage Time: 1.266 Sec

Torque

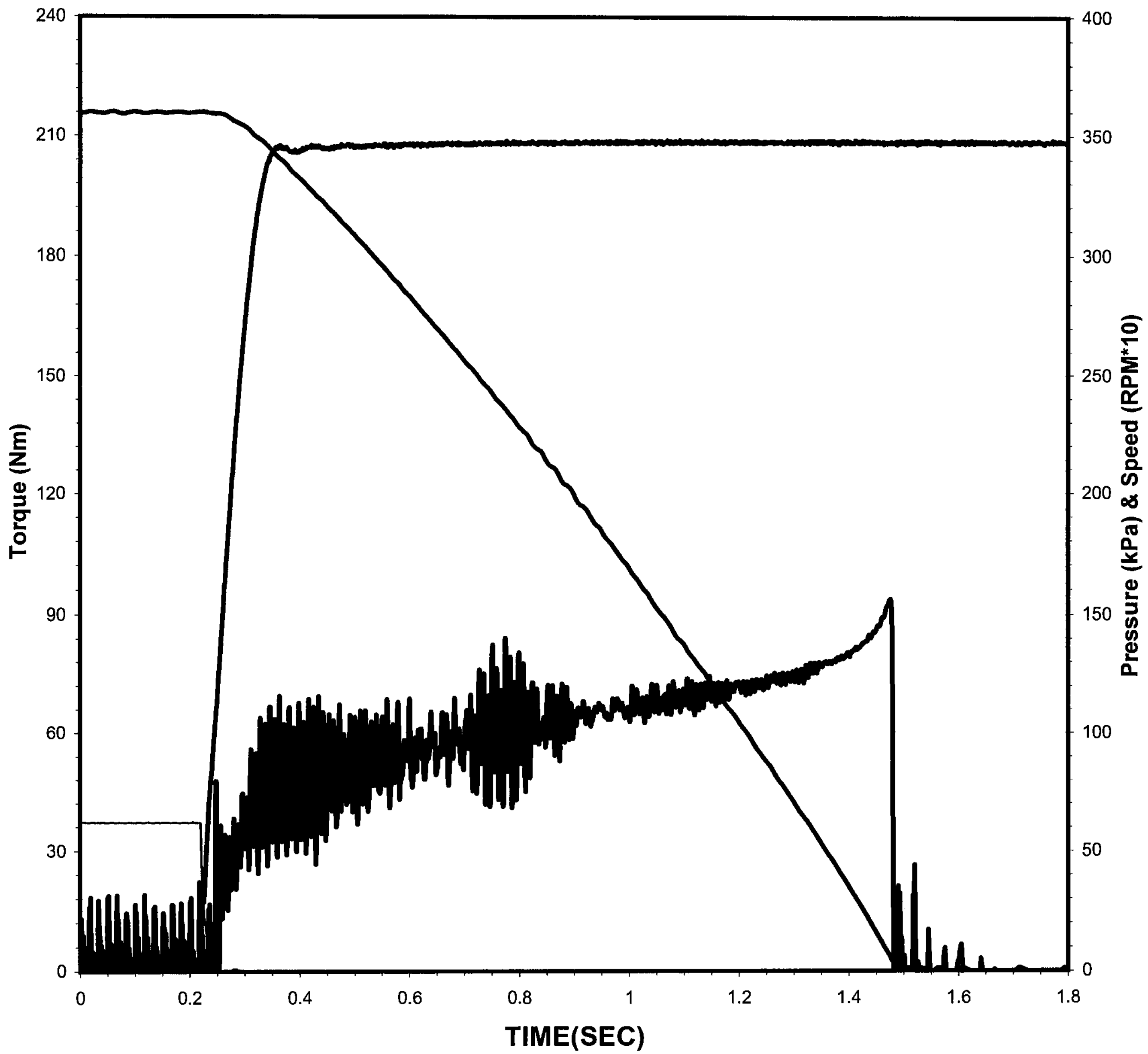
0.2 Sec Dyn:	49 N*m
Midpoint Dyn:	63 N*m
LwSpd Dynamic:	92 N*m

Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.153

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/19/2010

Time of Test: 13:50:32

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 500

Temperature: 93.8 °C
(93.3 ± 3.0 °C)
Apply Pressure: 349 kPa
(345 ± 7 KPa)
Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)
Energy: 14.2 KJ
(14.50 ± 0.40 KJ)
Engage Time: 1.261 Sec

Torque

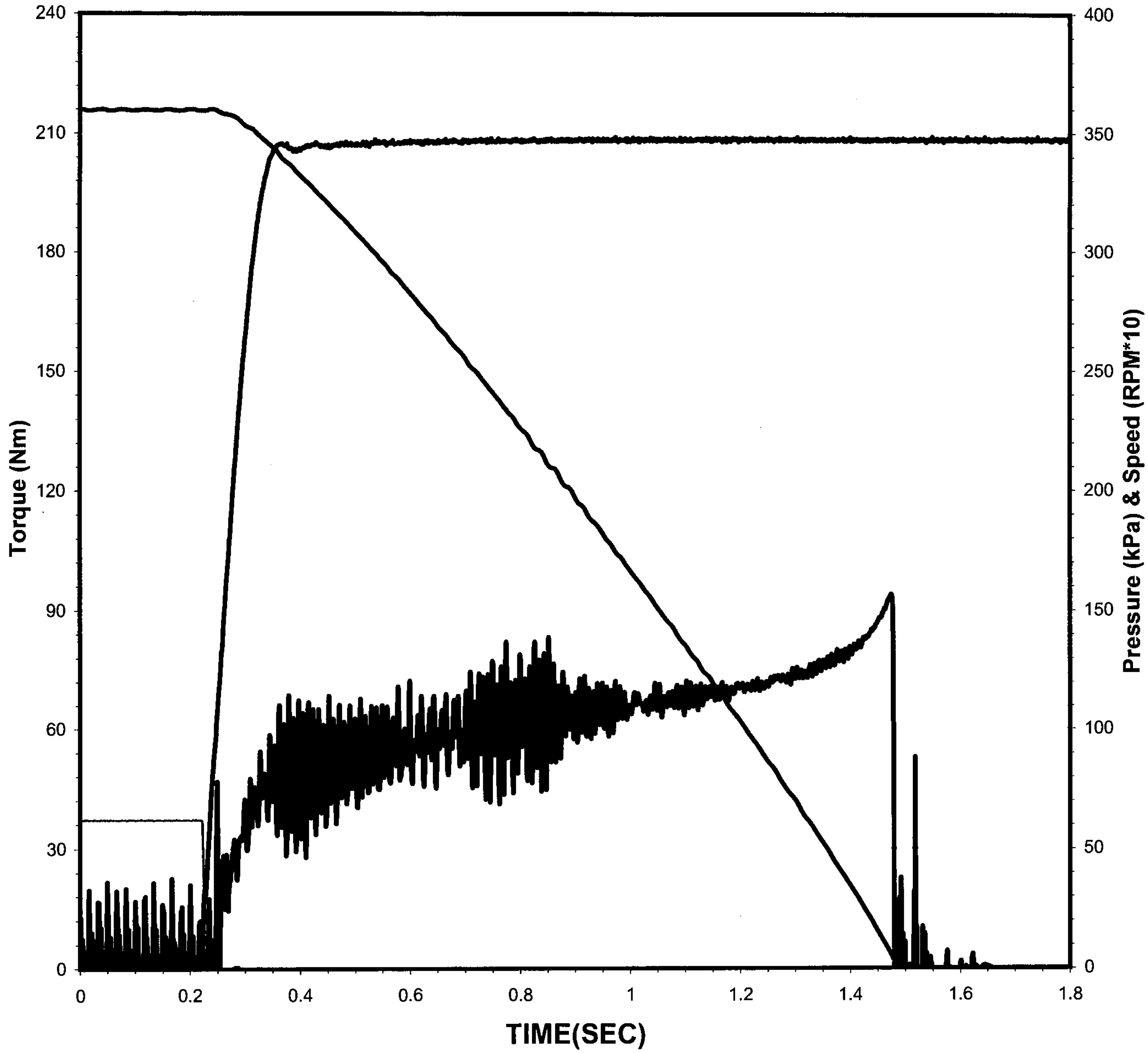
0.2 Sec Dyn:	50 N*m
Midpoint Dyn:	63 N*m
LwSpd Dynamic:	92 N*m

Coefficient of Friction

.2 Sec Dyn:	0.083
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.152

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/19/2010
Time of Test:	13:50:58
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	501
Temperature:	90.0 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	349 kPa
	(345 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	14.2 KJ
	(14.50 ± 0.40 KJ)
Engage Time:	1.256 Sec

Torque

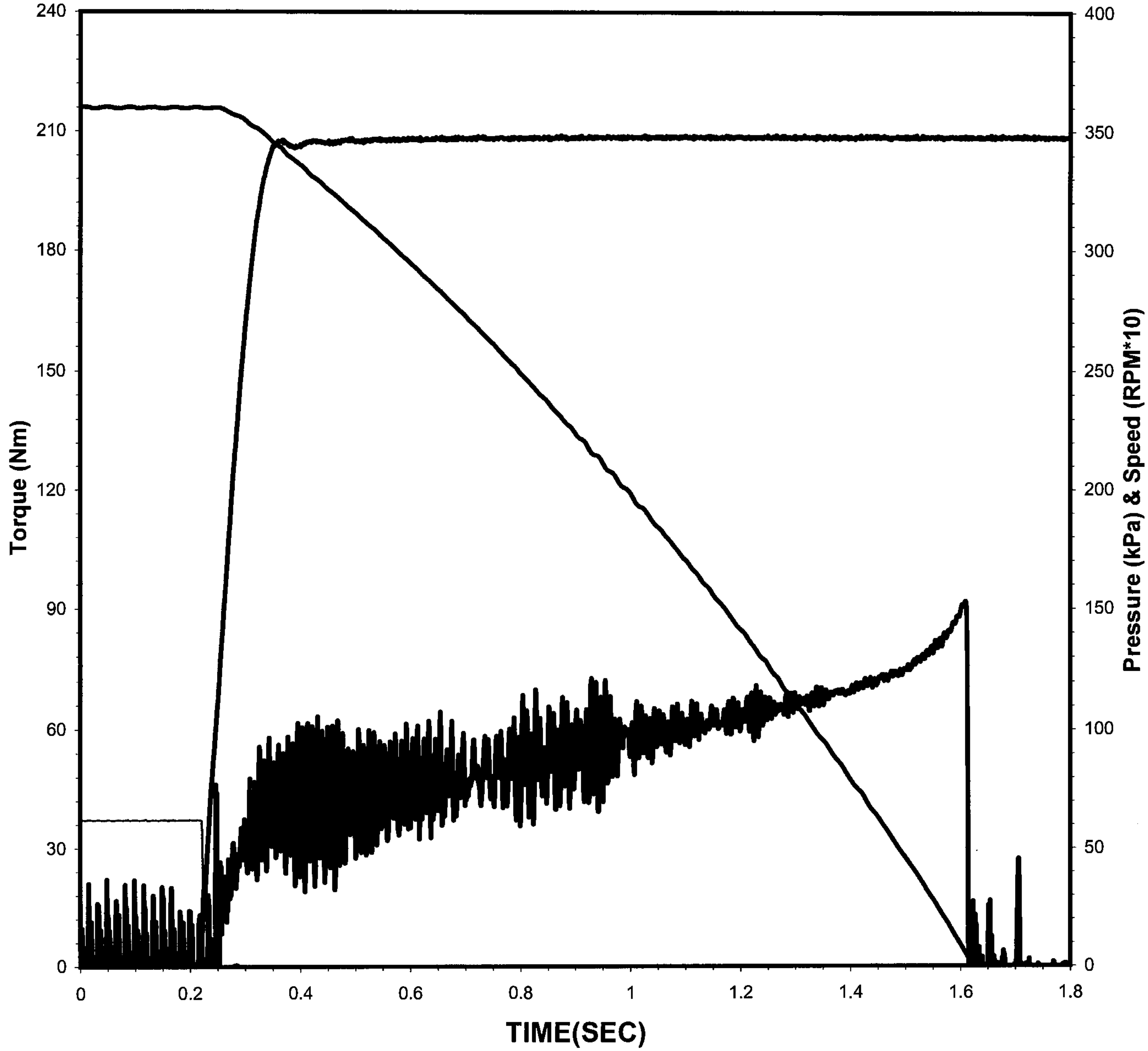
0.2 Sec Dyn:	49 N*m
Midpoint Dyn:	63 N*m
LwSpd Dynamic:	94 N*m

Coefficient of Friction

.2 Sec Dyn:	0.081
Midpoint Dyn:	0.105
LwSpd Dynamic:	0.156

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	**7/19/2010**
Time of Test:	**15:55:13**
Test Number:	**C4-6-1284**
Fluid Code:	**LO250033**
Cycle Number:	**998**
Temperature:	**93.6 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**349 kPa** (345 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**14.2 KJ** (14.50 ± 0.40 KJ)
Engage Time:	**1.393 Sec**

Torque

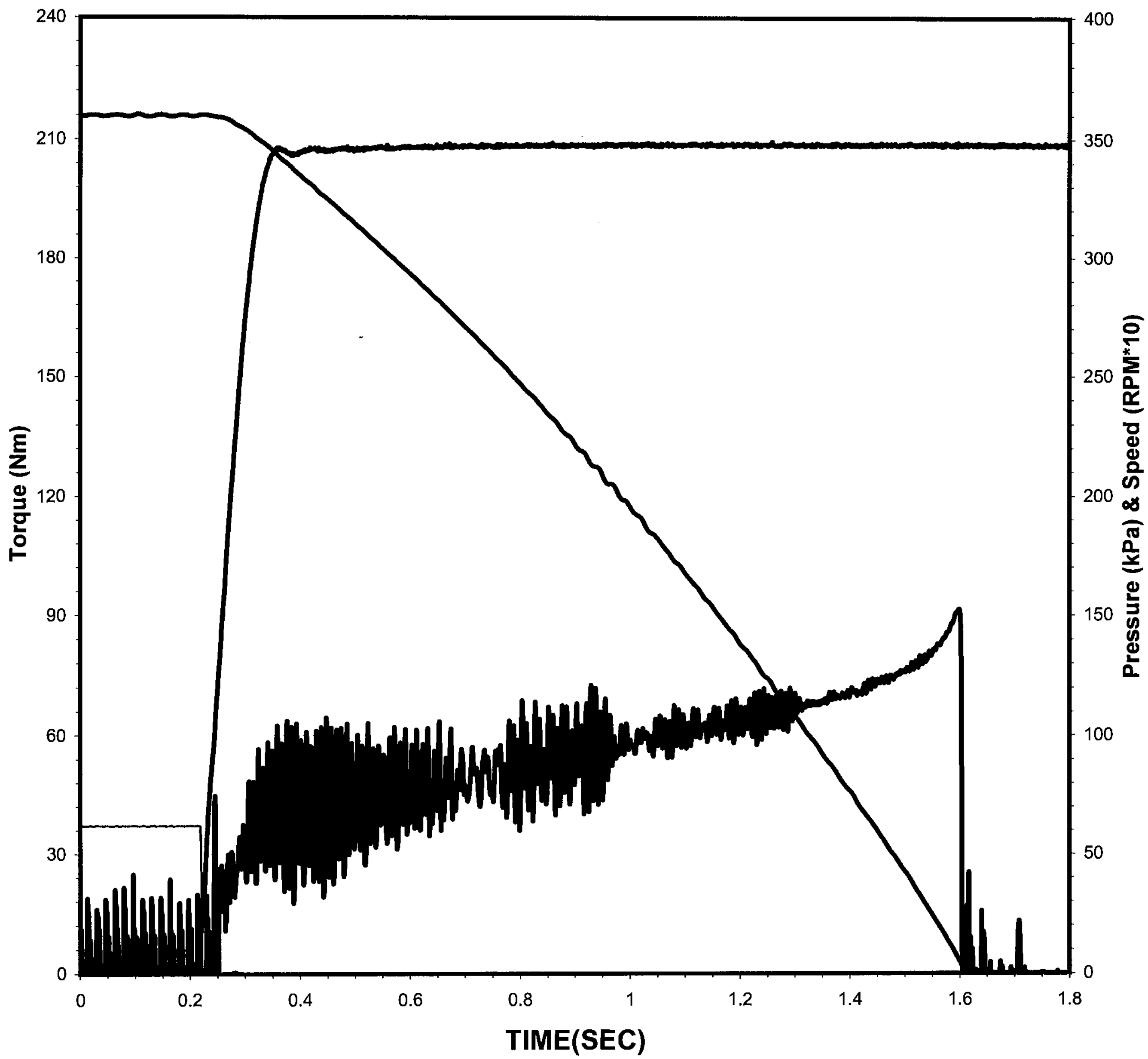
0.2 Sec Dyn:	**41 N*m**
Midpoint Dyn:	**57 N*m**
LwSpd Dynamic:	**92 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.068**
Midpoint Dyn:	**0.094**
LwSpd Dynamic:	**0.153**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/19/2010

Time of Test: 15:55:29

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 999

Temperature: 93.7 °C
(93.3 ± 3.0 °C)

Apply Pressure: 349 kPa
(345 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 14.2 KJ
(14.50 ± 0.40 KJ)

Engage Time: 1.384 Sec

Torque

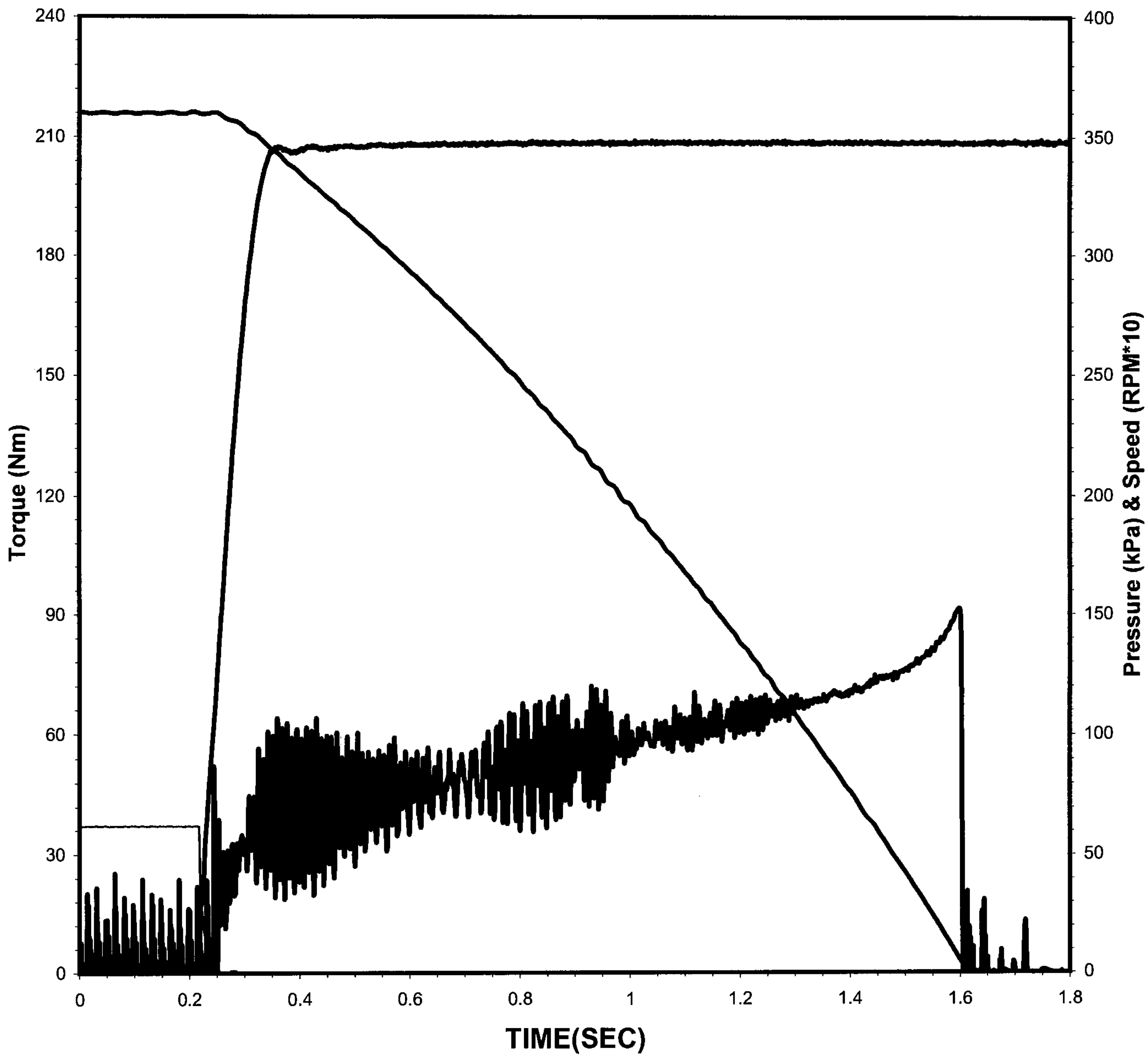
0.2 Sec Dyn:	42 N*m
Midpoint Dyn:	55 N*m
LwSpd Dynamic:	92 N*m

Coefficient of Friction

.2 Sec Dyn:	0.069
Midpoint Dyn:	0.092
LwSpd Dynamic:	0.152

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/19/2010
Time of Test:	15:55:44
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	1000
Temperature:	93.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	349 kPa (345 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	14.2 KJ (14.50 ± 0.40 KJ)
Engage Time:	1.386 Sec

Torque

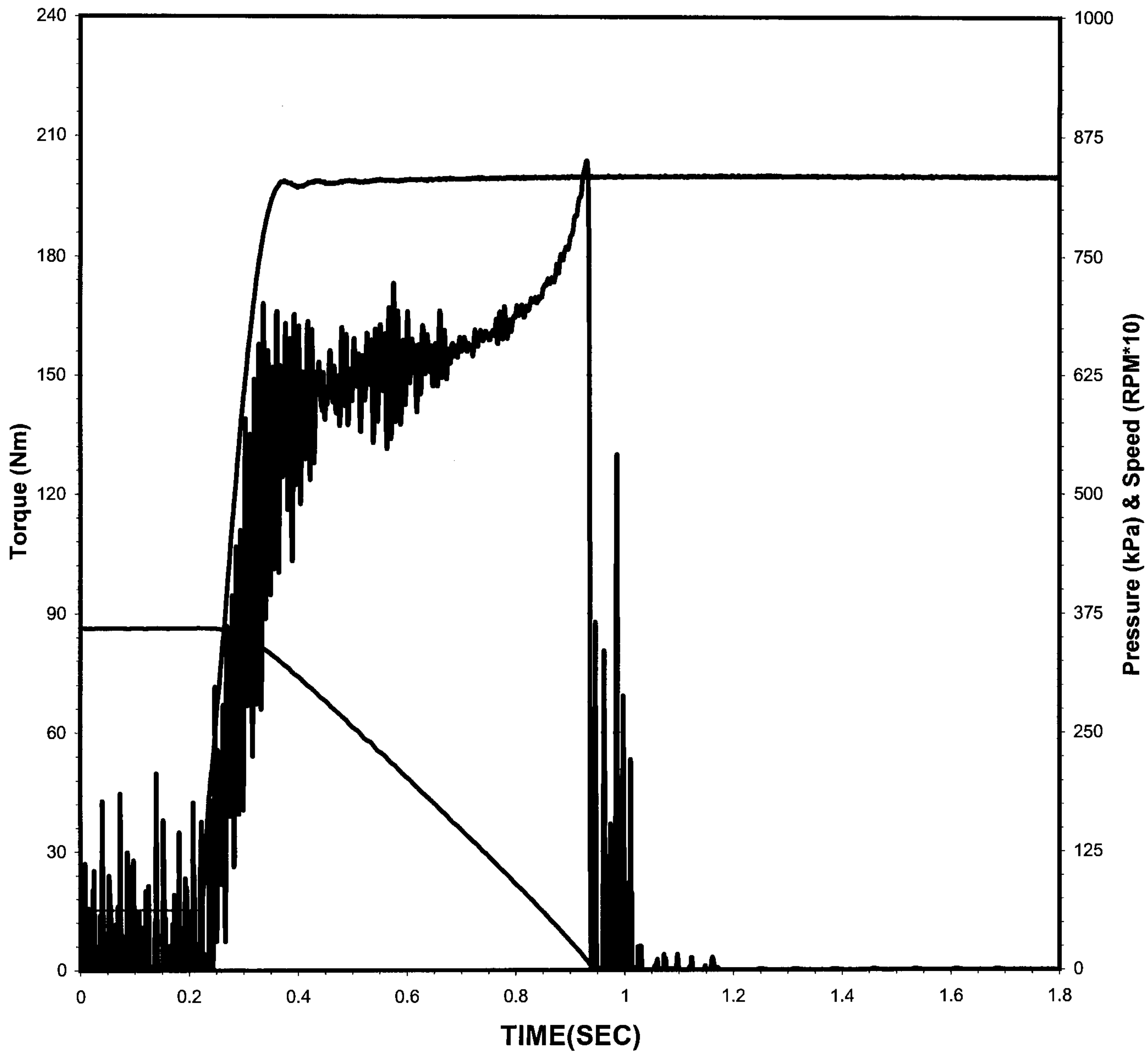
0.2 Sec Dyn:	41 N*m
Midpoint Dyn:	56 N*m
LwSpd Dynamic:	90 N*m

Coefficient of Friction

.2 Sec Dyn:	0.069
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.149

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/19/2010

Time of Test: 16:04:38

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 1010

Temperature: 99.2 °C
(112.7 ± 3.0 °C)

Apply Pressure: 830 kPa
827 ± 7 KPa)

Apply Rate: 0.15 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.72 Sec

Torque

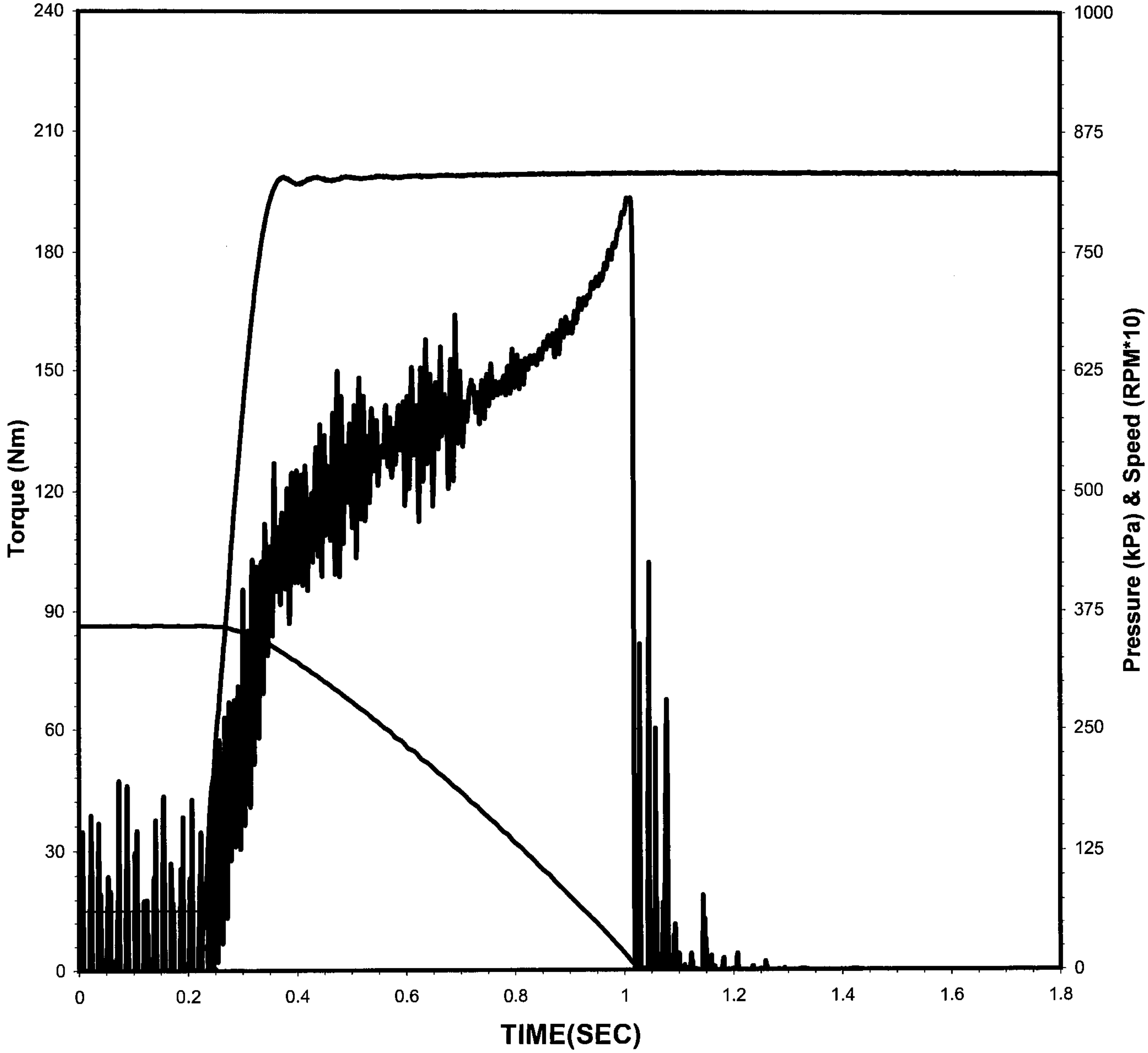
0.2 Sec Dyn: 145 N*m
Midpoint Dyn: 152 N*m
LwSpd Dynamic: 198 N*m

Coefficient of Friction

.2 Sec Dyn: 0.100
Midpoint Dyn: 0.105
LwSpd Dynamic: 0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/19/2010

Time of Test: 18:06:53

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 1499

Temperature: 112.9 °C
(112.7 ± 3.0 °C)

Apply Pressure: 831 kPa
827 ± 7 KPa)

Apply Rate: 0.15 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.795 Sec

Torque

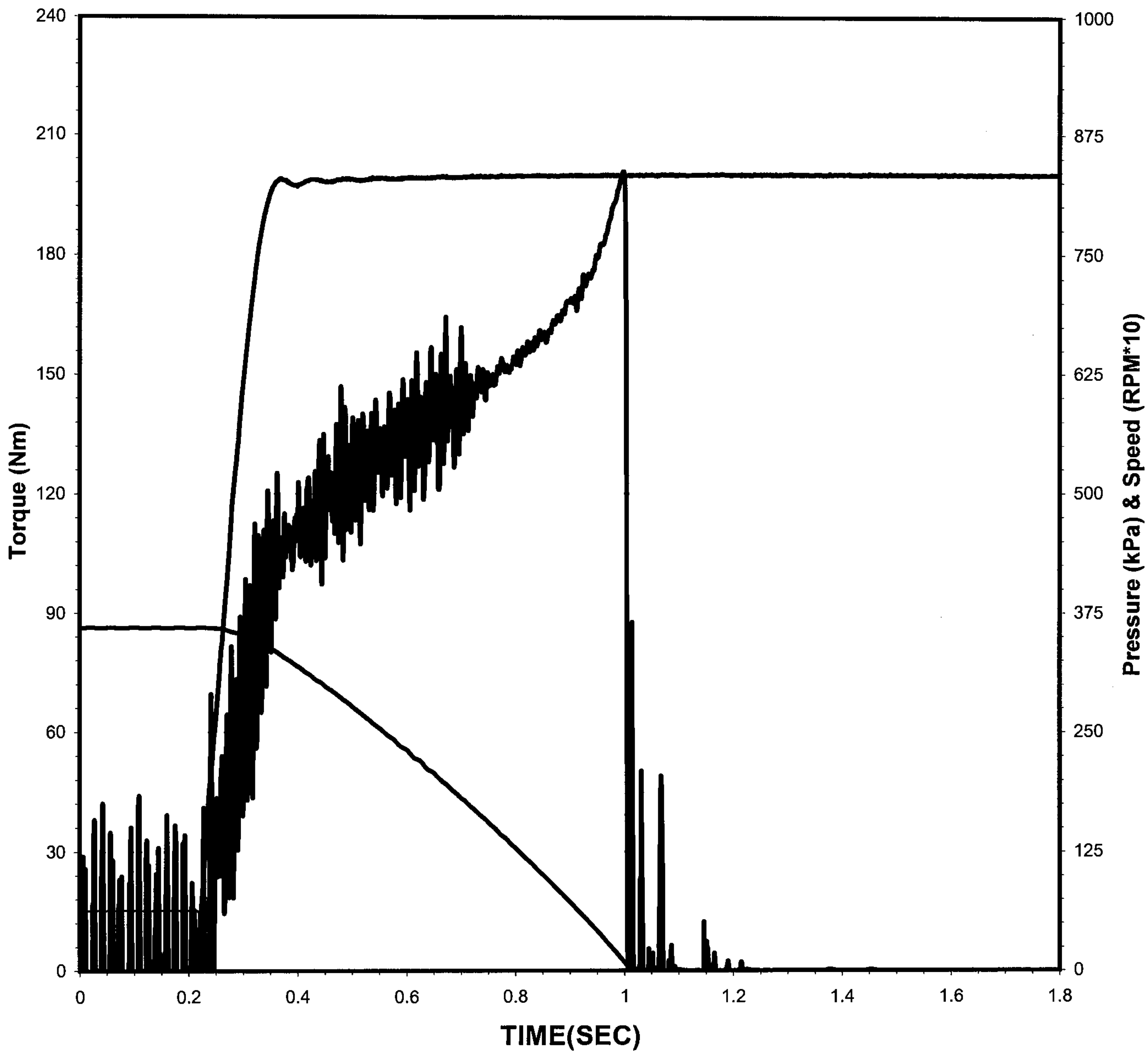
0.2 Sec Dyn:	113 N*m
Midpoint Dyn:	136 N*m
LwSpd Dynamic:	188 N*m

Coefficient of Friction

.2 Sec Dyn:	0.078
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.130

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/19/2010
Time of Test:	18:07:08
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	1500
Temperature:	113.1 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.15 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.788 Sec

Torque

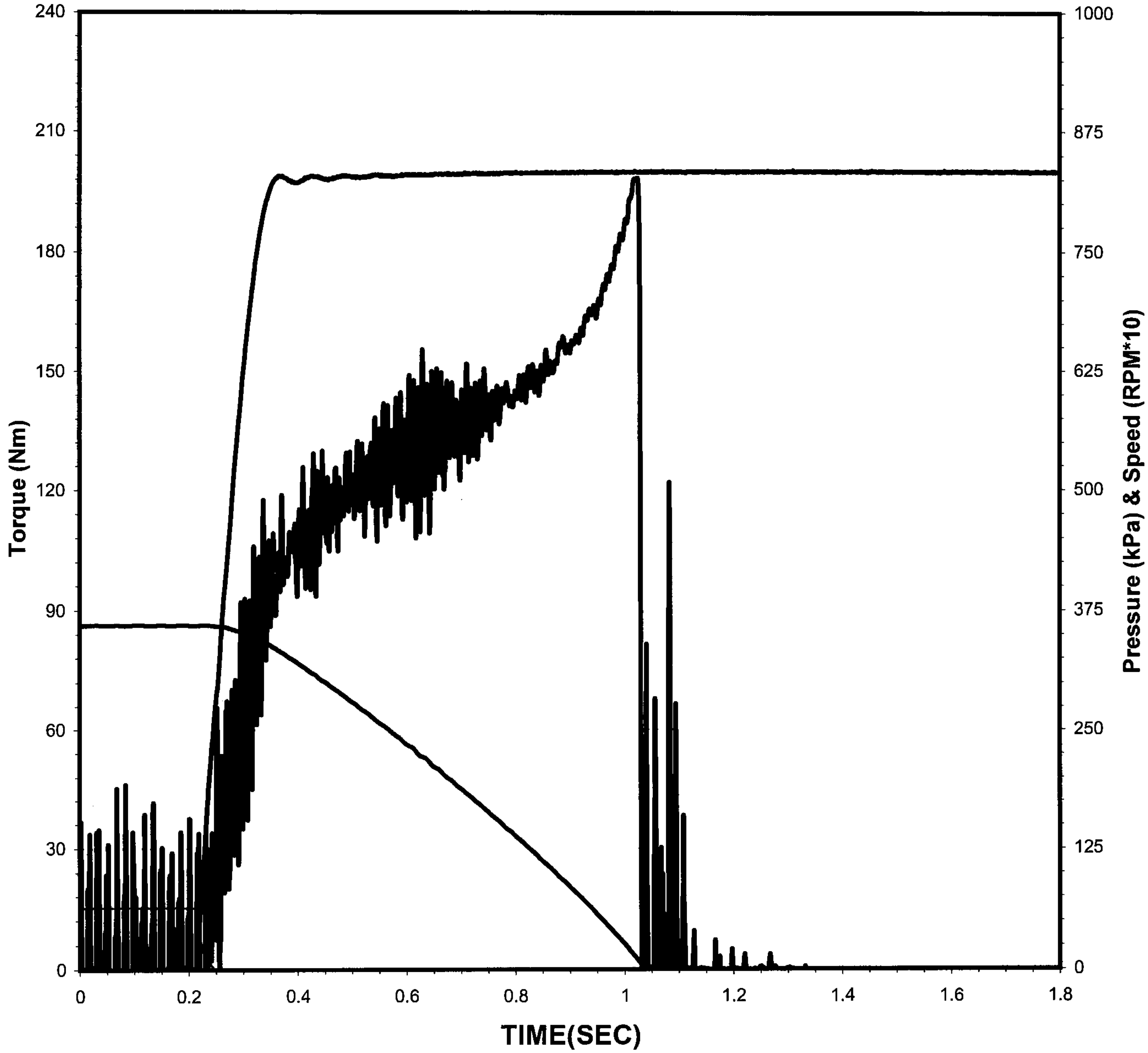
0.2 Sec Dyn:	115 N*m
Midpoint Dyn:	136 N*m
LwSpd Dynamic:	194 N*m

Coefficient of Friction

.2 Sec Dyn:	0.080
Midpoint Dyn:	0.094
LwSpd Dynamic:	0.134

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/19/2010
Time of Test:	18:07:35
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	1501
Temperature:	109.0 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	831 kPa
	827 ± 7 KPa)
Apply Rate:	0.15 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.814 Sec

Torque

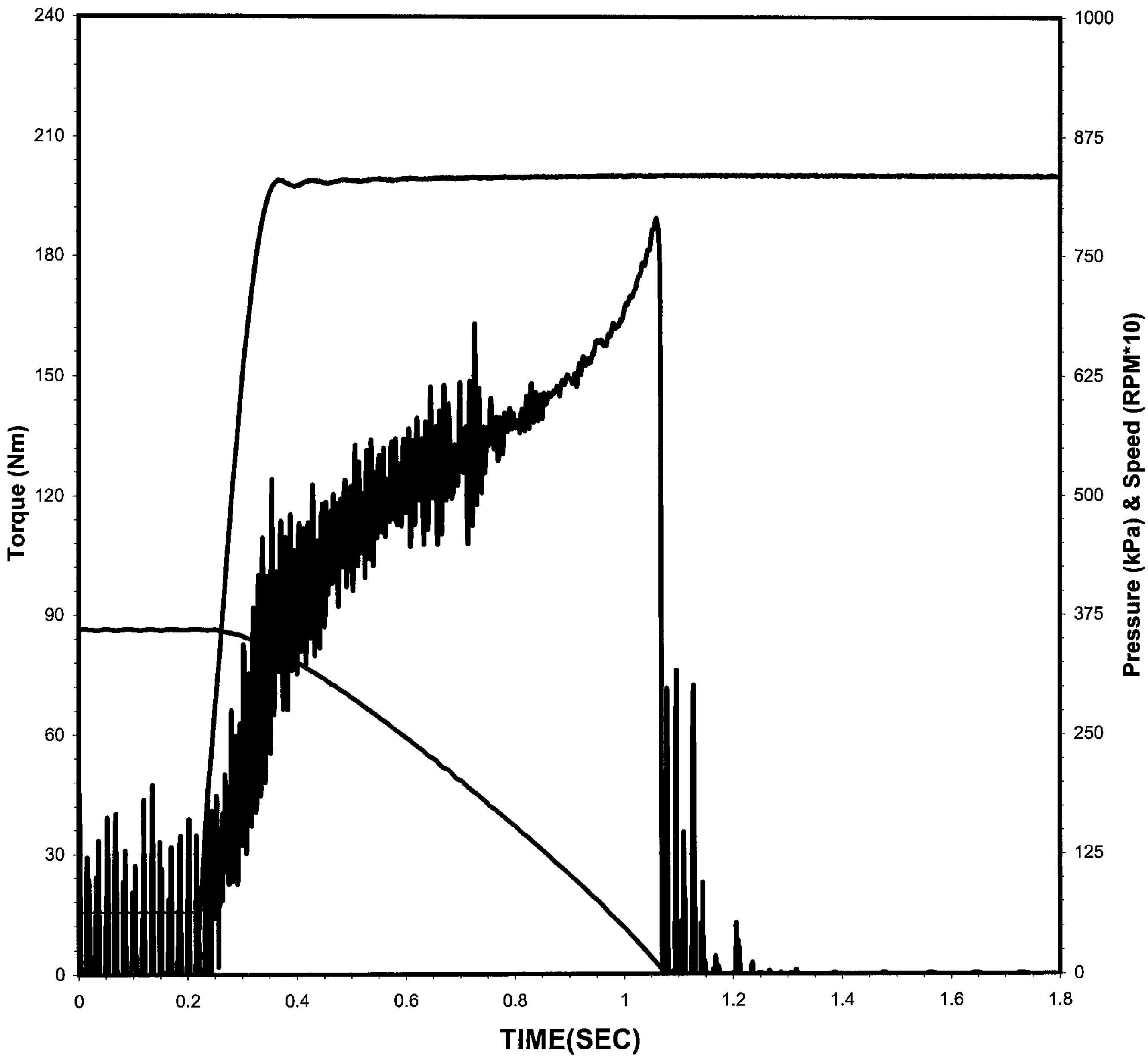
0.2 Sec Dyn:	110 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	195 N*m

Coefficient of Friction

.2 Sec Dyn:	0.076
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.135

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/19/2010

Time of Test: 20:12:05

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 1999

Temperature: 113.1 °C (112.7 ± 3.0 °C)

Apply Pressure: 832 kPa 827 ± 7 KPa)

Apply Rate: 0.15 Sec (0.15 ± 0.02 Sec)

Energy: 18.4 KJ (18.71 ± 0.40 KJ)

Engage Time: 0.853 Sec

Torque

0.2 Sec Dyn: 98 N*m

Midpoint Dyn: 128 N*m

LwSpd Dynamic: 180 N*m

Coefficient of Friction

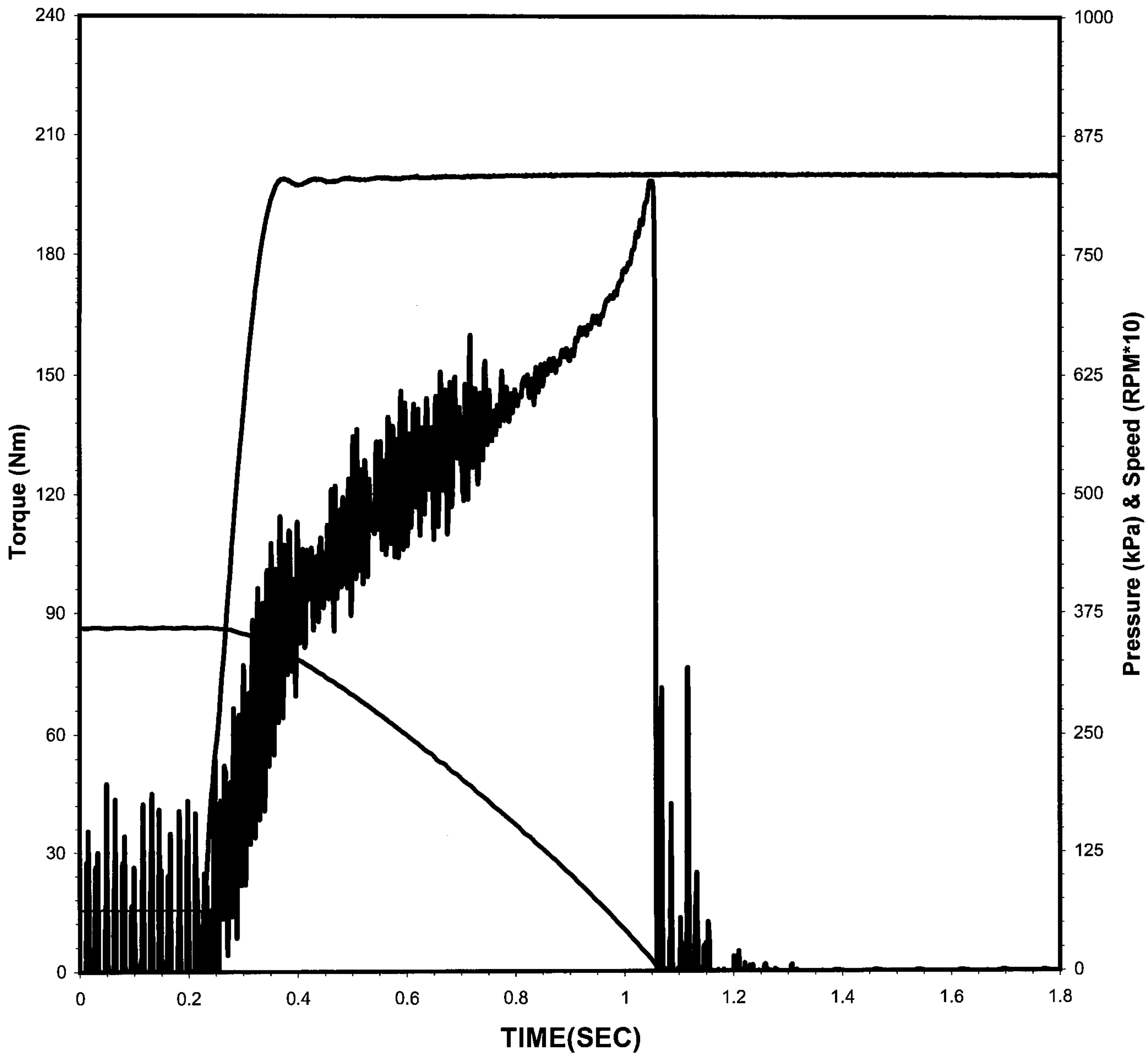
.2 Sec Dyn: 0.068

Midpoint Dyn: 0.088

LwSpd Dynamic: 0.124

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/19/2010

Time of Test: 20:12:20

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 2000

Temperature: 113.5 °C
(112.7 ± 3.0 °C)

Apply Pressure: 832 kPa
827 ± 7 KPa)

Apply Rate: 0.15 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.836 Sec

Torque

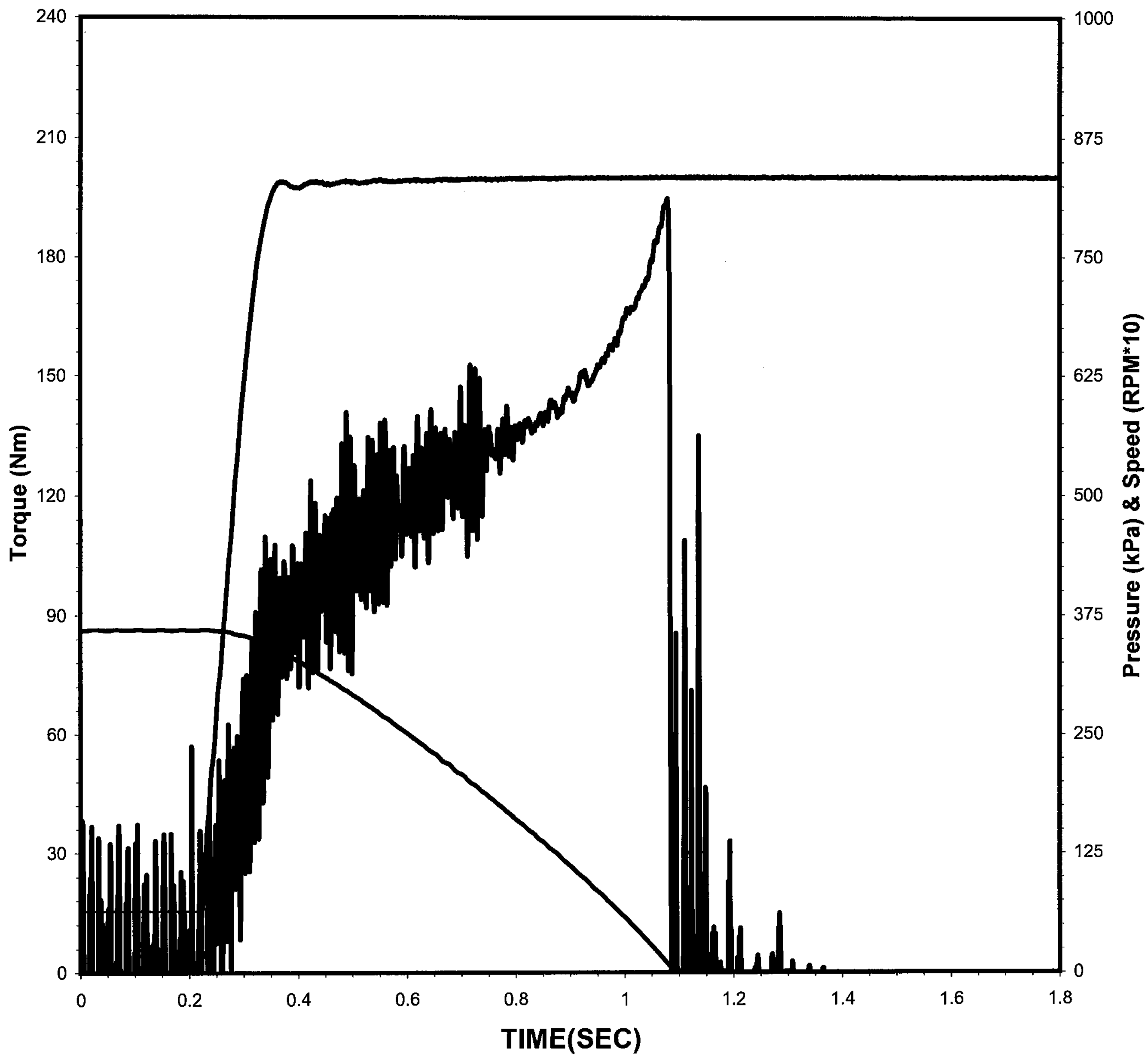
0.2 Sec Dyn:	99 N*m
Midpoint Dyn:	129 N*m
LwSpd Dynamic:	194 N*m

Coefficient of Friction

.2 Sec Dyn:	0.068
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.134

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/19/2010

Time of Test: 20:12:46

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 2001

Temperature: 108.8 °C
(112.7 ± 3.0 °C)

Apply Pressure: 832 kPa
827 ± 7 KPa)

Apply Rate: 0.15 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.867 Sec

Torque

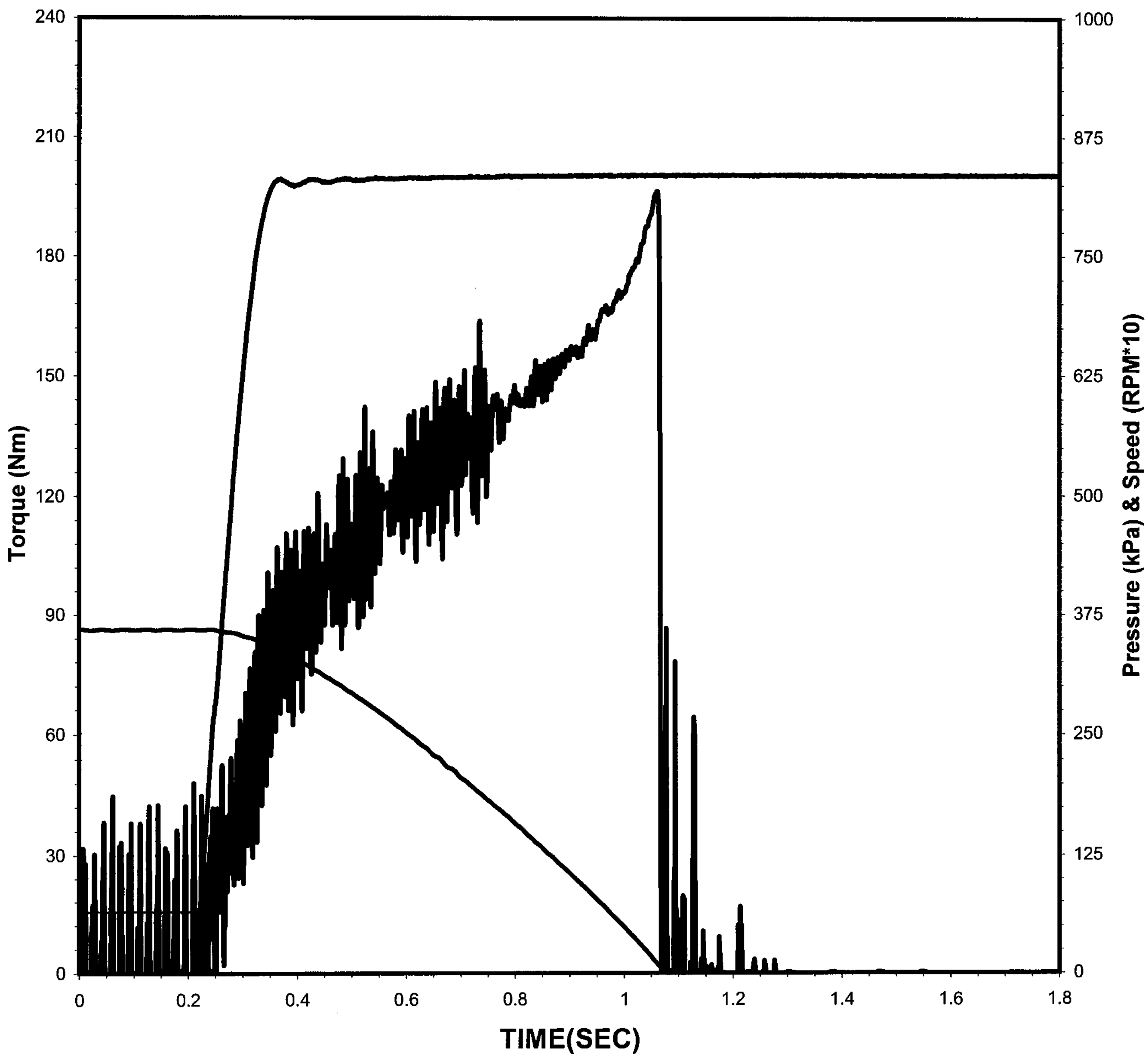
0.2 Sec Dyn:	95 N*m
Midpoint Dyn:	125 N*m
LwSpd Dynamic:	191 N*m

Coefficient of Friction

.2 Sec Dyn:	0.066
Midpoint Dyn:	0.086
LwSpd Dynamic:	0.132

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/19/2010
Time of Test:	22:17:16
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	2499
Temperature:	113.2 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	833 kPa
	827 ± 7 KPa)
Apply Rate:	0.15 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.851 Sec

Torque

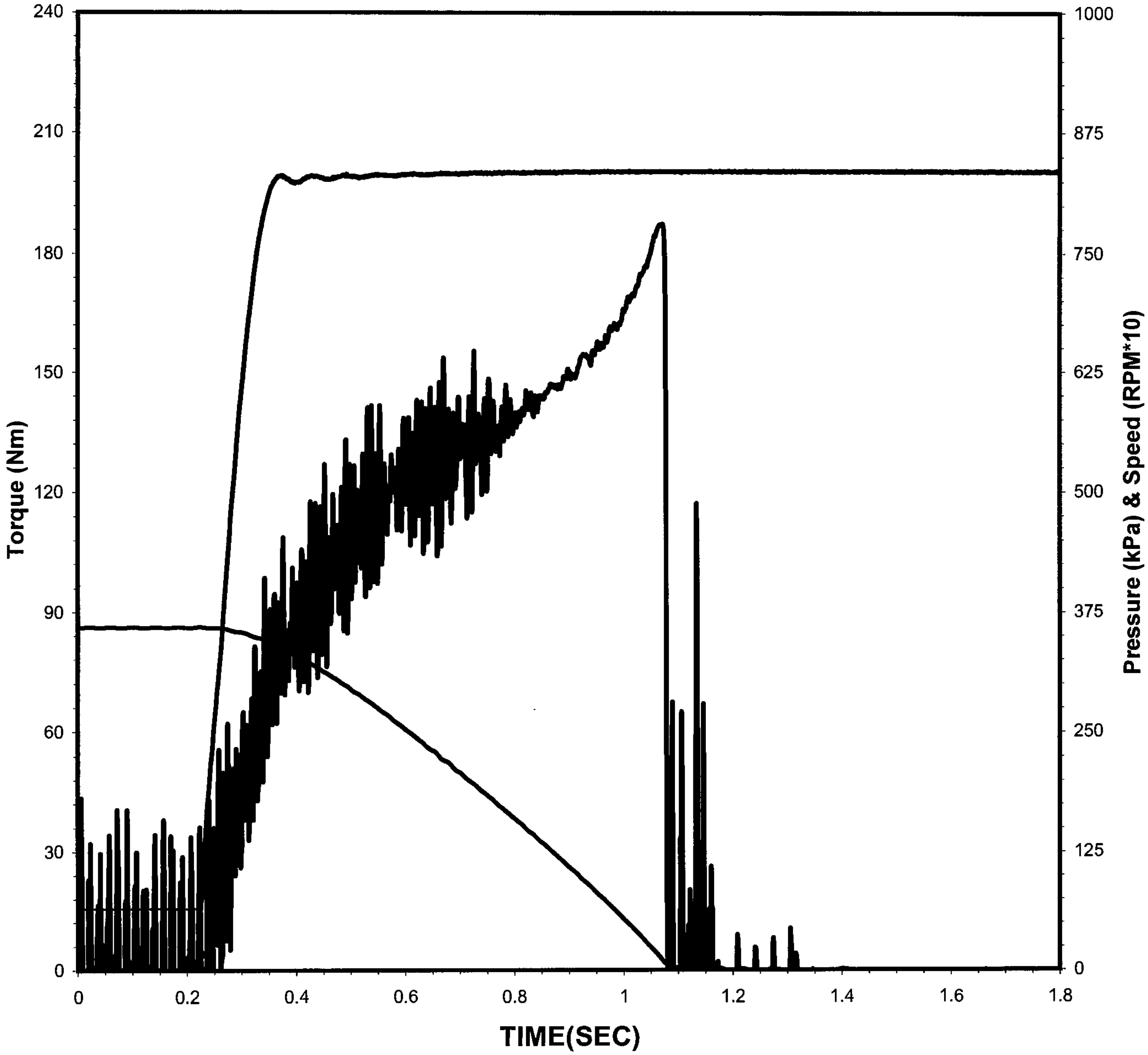
0.2 Sec Dyn:	93 N*m
Midpoint Dyn:	127 N*m
LwSpd Dynamic:	194 N*m

Coefficient of Friction

.2 Sec Dyn:	0.064
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.134

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/19/2010**
Time of Test:	**22:17:32**
Test Number:	**C4-6-1284**
Fluid Code:	**LO250033**
Cycle Number:	**2500**
Temperature:	**113.3 °C**
	(112.7 ± 3.0 °C)
Apply Pressure:	**833 kPa**
	827 ± 7 KPa)
Apply Rate:	**0.15 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.4 KJ**
	(18.71 ± 0.40 KJ)
Engage Time:	**0.86 Sec**

Torque

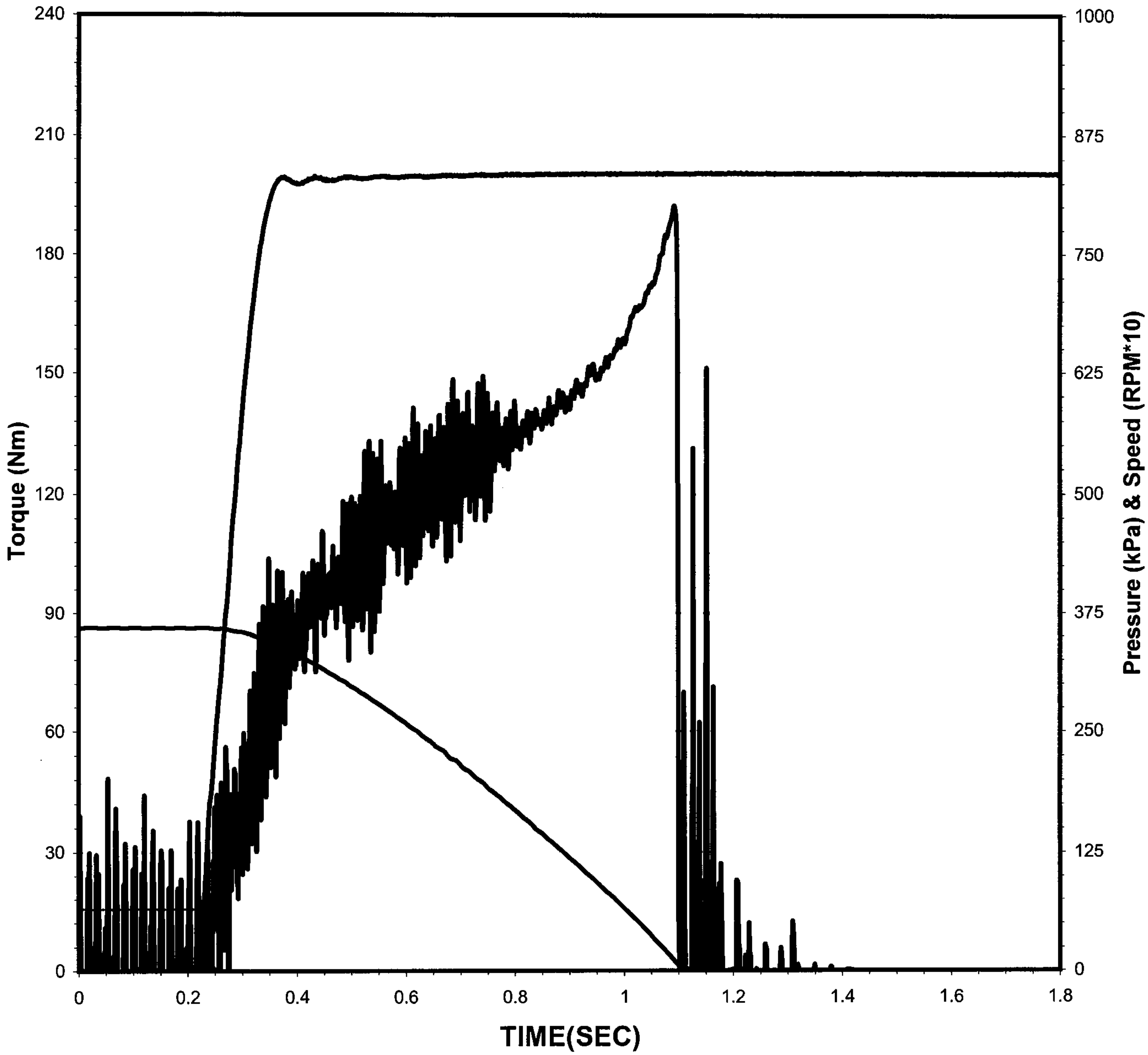
0.2 Sec Dyn:	**92 N*m**
Midpoint Dyn:	**128 N*m**
LwSpd Dynamic:	**180 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.064**
Midpoint Dyn:	**0.089**
LwSpd Dynamic:	**0.124**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/19/2010

Time of Test: 22:17:58

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 2501

Temperature: 109.2 °C
(112.7 ± 3.0 °C)

Apply Pressure: 833 kPa
827 ± 7 KPa)

Apply Rate: 0.15 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.878 Sec

Torque

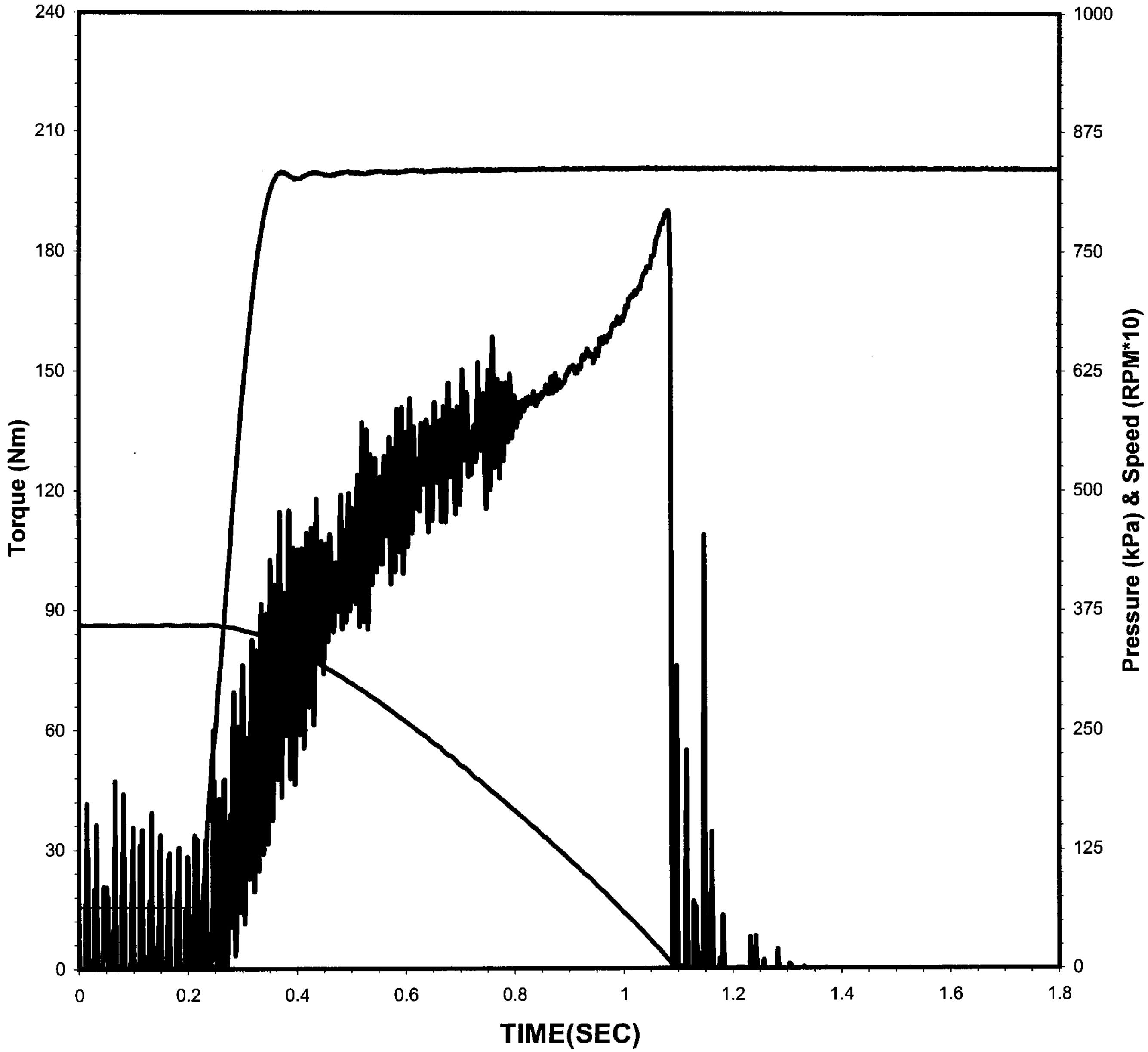
0.2 Sec Dyn:	93 N*m
Midpoint Dyn:	124 N*m
LwSpd Dynamic:	186 N*m

Coefficient of Friction

.2 Sec Dyn:	0.064
Midpoint Dyn:	0.085
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	0:22:28
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	2999
Temperature:	113.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	834 kPa 827 ± 7 KPa)
Apply Rate:	0.15 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.867 Sec

Torque

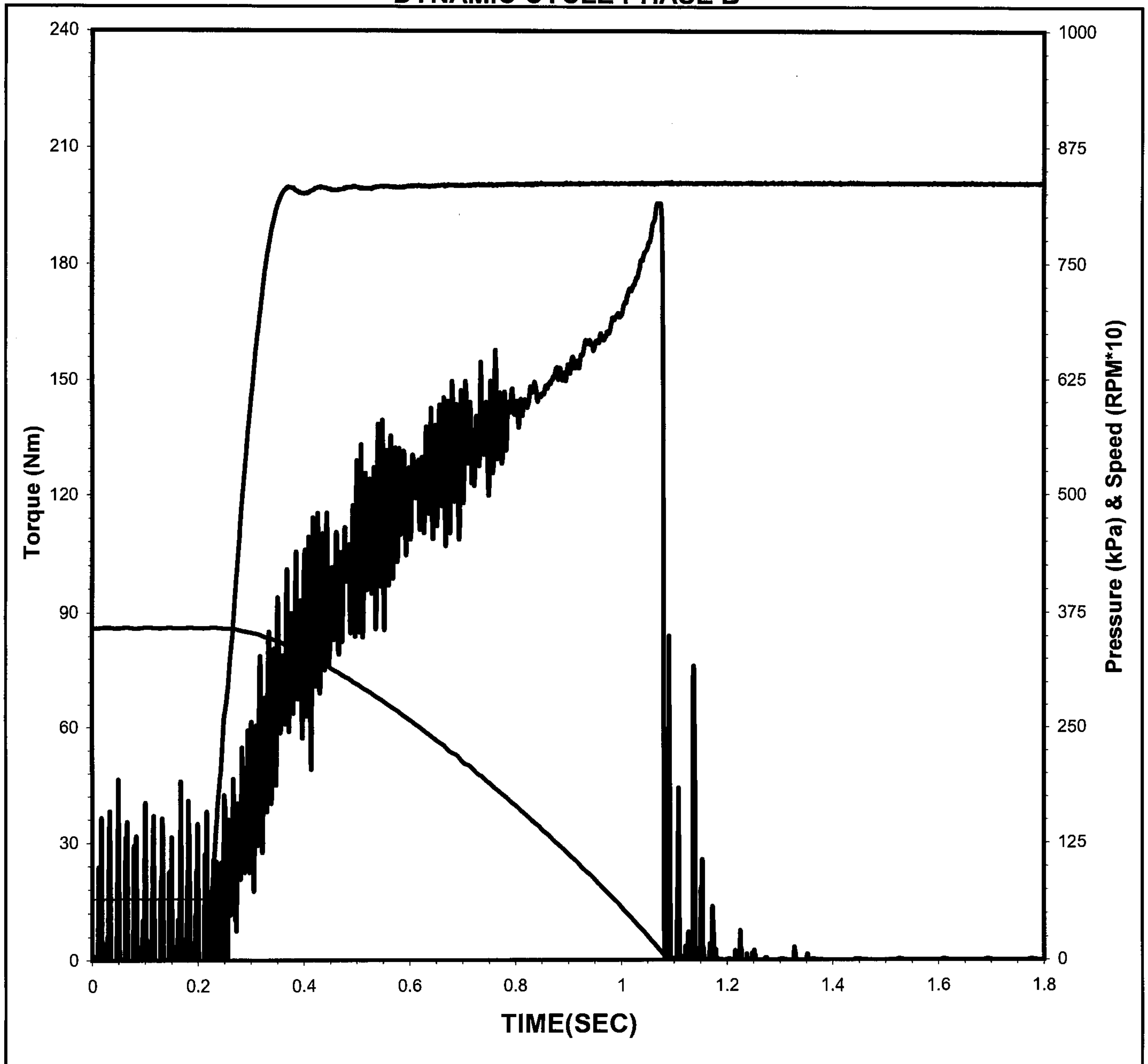
0.2 Sec Dyn:	88 N*m
Midpoint Dyn:	128 N*m
LwSpd Dynamic:	183 N*m

Coefficient of Friction

.2 Sec Dyn:	0.061
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/20/2010

Time of Test: 0:22:43

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 3000

Temperature: 113.2 °C
(112.7 ± 3.0 °C)

Apply Pressure: 834 kPa
827 ± 7 KPa)

Apply Rate: 0.15 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.862 Sec

Torque

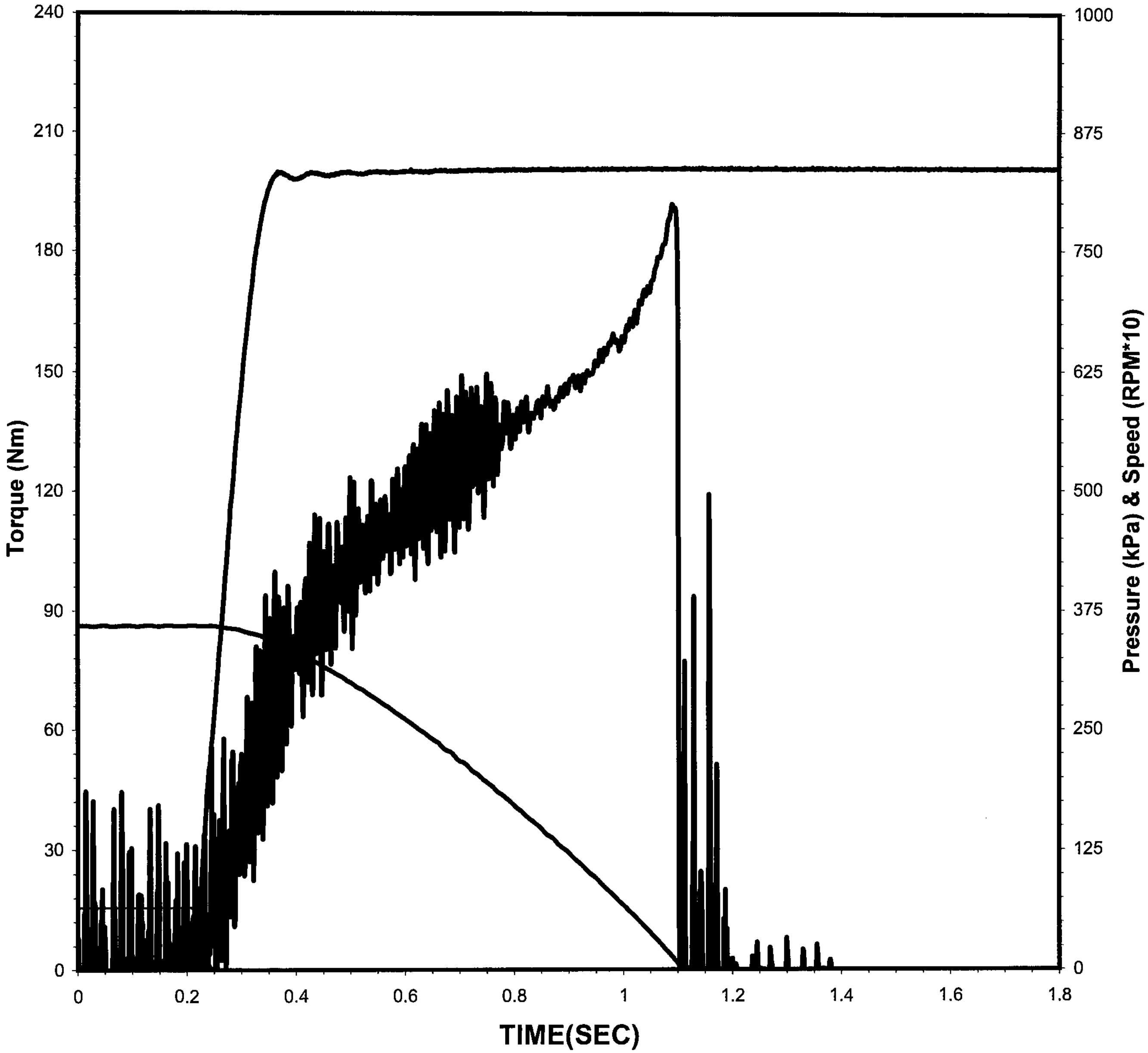
0.2 Sec Dyn:	87 N*m
Midpoint Dyn:	127 N*m
LwSpd Dynamic:	189 N*m

Coefficient of Friction

.2 Sec Dyn:	0.060
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.131

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: **7/20/2010**

Time of Test: **0:23:10**

Test Number: **C4-6-1284**

Fluid Code: **LO250033**

Cycle Number: **3001**

Temperature: **109.4 °C** (112.7 ± 3.0 °C)

Apply Pressure: **834 kPa** 827 ± 7 KPa)

Apply Rate: **0.15 Sec** (0.15 ± 0.02 Sec)

Energy: **18.4 KJ** (18.71 ± 0.40 KJ)

Engage Time: **0.884 Sec**

Torque

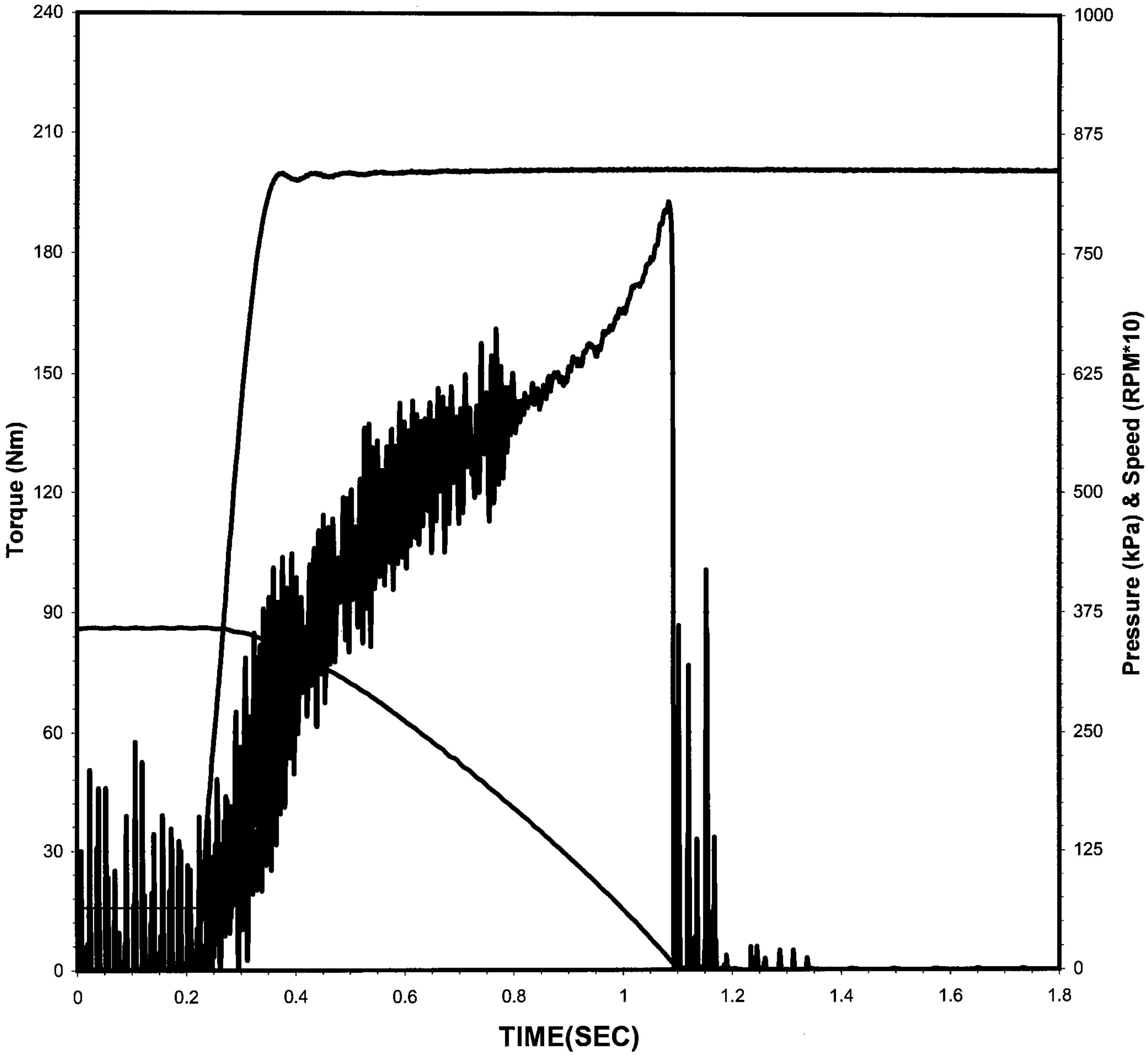
0.2 Sec Dyn:	**87 N*m**
Midpoint Dyn:	**124 N*m**
LwSpd Dynamic:	**185 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.060**
Midpoint Dyn:	**0.085**
LwSpd Dynamic:	**0.128**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	2:27:40
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	3499
Temperature:	113.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	835 kPa 827 ± 7 KPa)
Apply Rate:	0.15 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.87 Sec

Torque

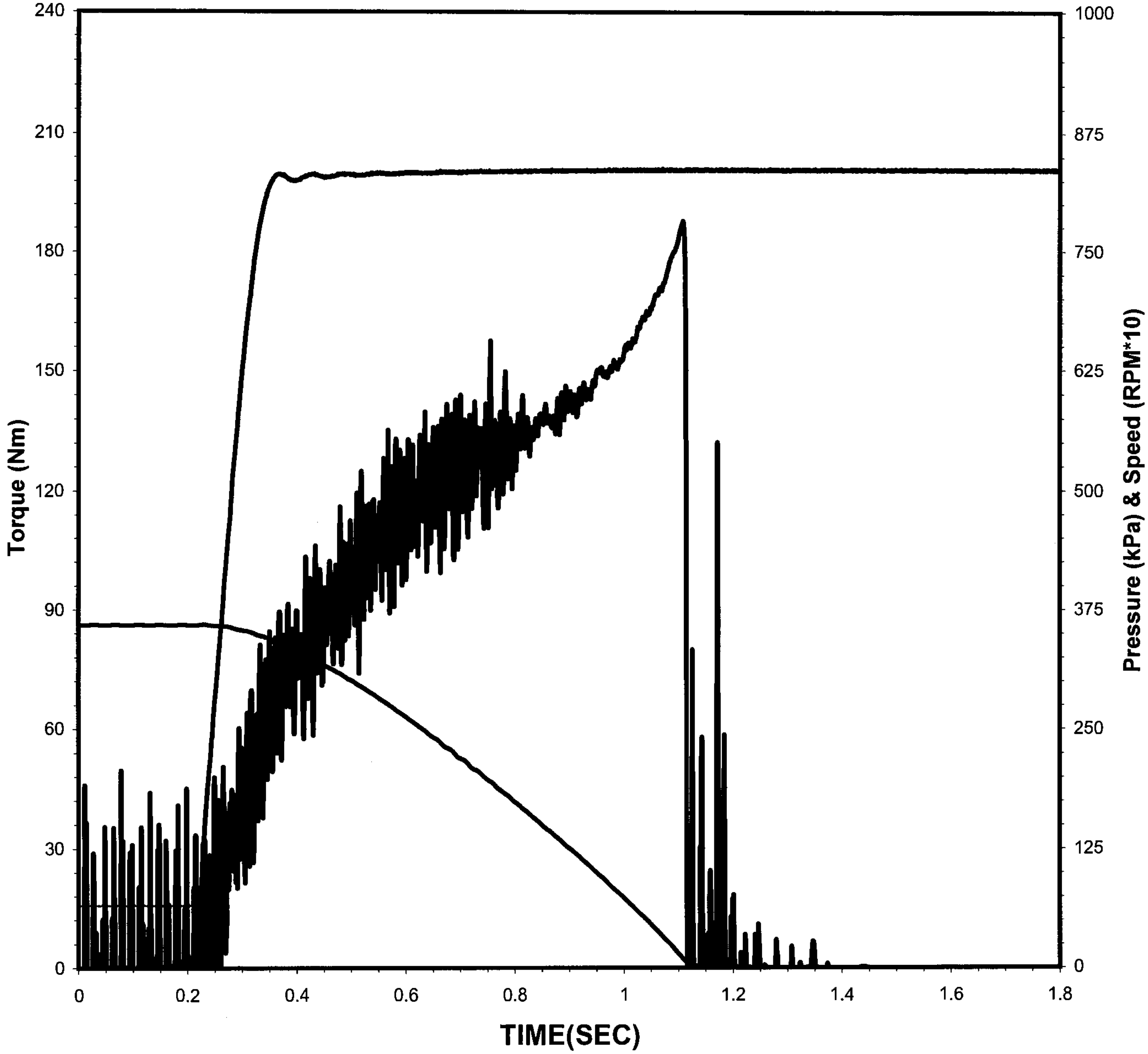
0.2 Sec Dyn:	83 N*m
Midpoint Dyn:	127 N*m
LwSpd Dynamic:	184 N*m

Coefficient of Friction

.2 Sec Dyn:	0.057
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/20/2010

Time of Test: 2:27:55

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 3500

Temperature: 113.4 °C
(112.7 ± 3.0 °C)

Apply Pressure: 835 kPa
827 ± 7 KPa)

Apply Rate: 0.15 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.899 Sec

Torque

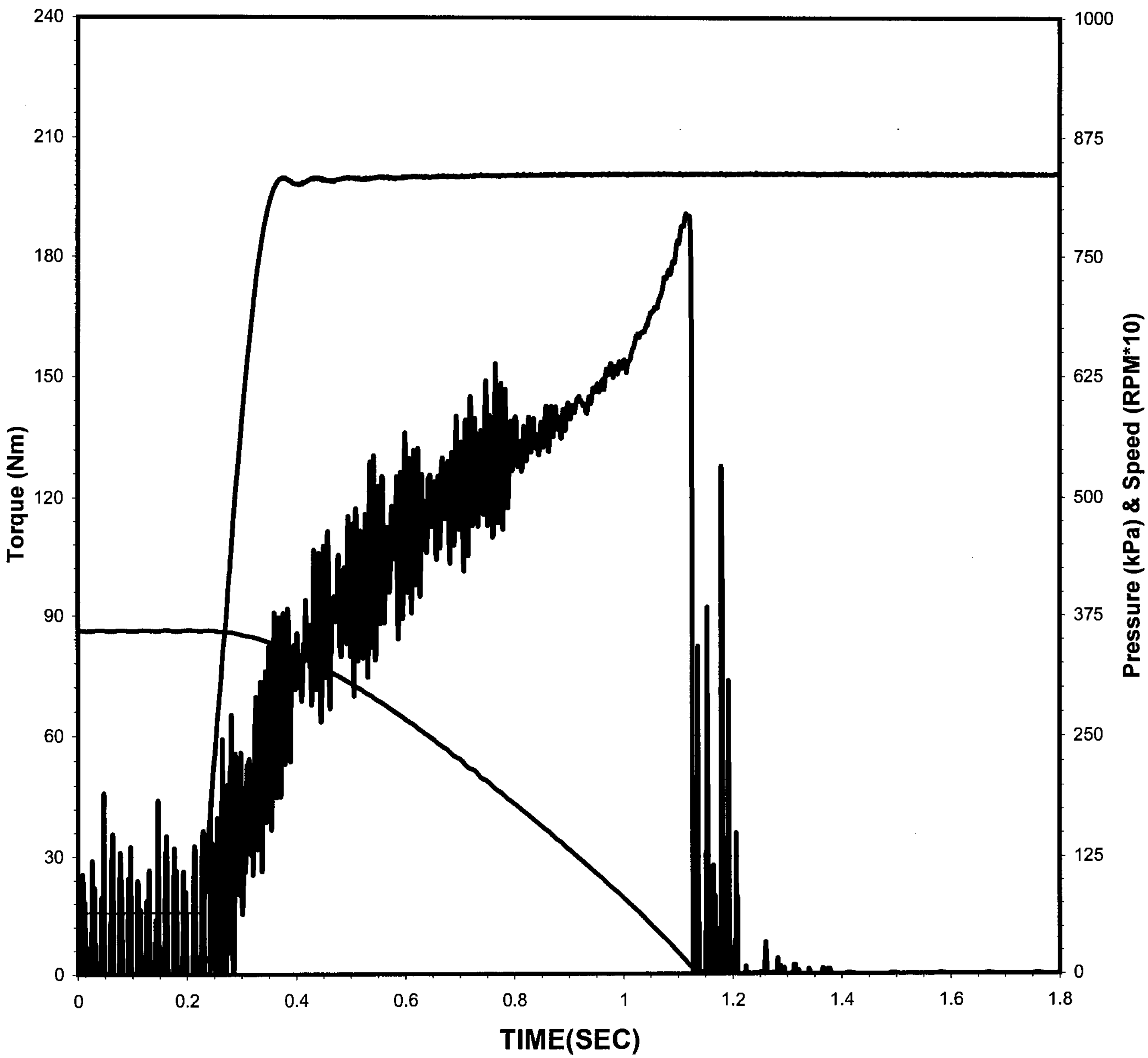
0.2 Sec Dyn:	82 N*m
Midpoint Dyn:	123 N*m
LwSpd Dynamic:	183 N*m

Coefficient of Friction

.2 Sec Dyn:	0.057
Midpoint Dyn:	0.085
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/20/2010**
Time of Test:	**2:28:22**
Test Number:	**C4-6-1284**
Fluid Code:	**LO250033**
Cycle Number:	**3501**
Temperature:	**109.2 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**835 kPa** 827 ± 7 KPa)
Apply Rate:	**0.15 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.903 Sec**

Torque

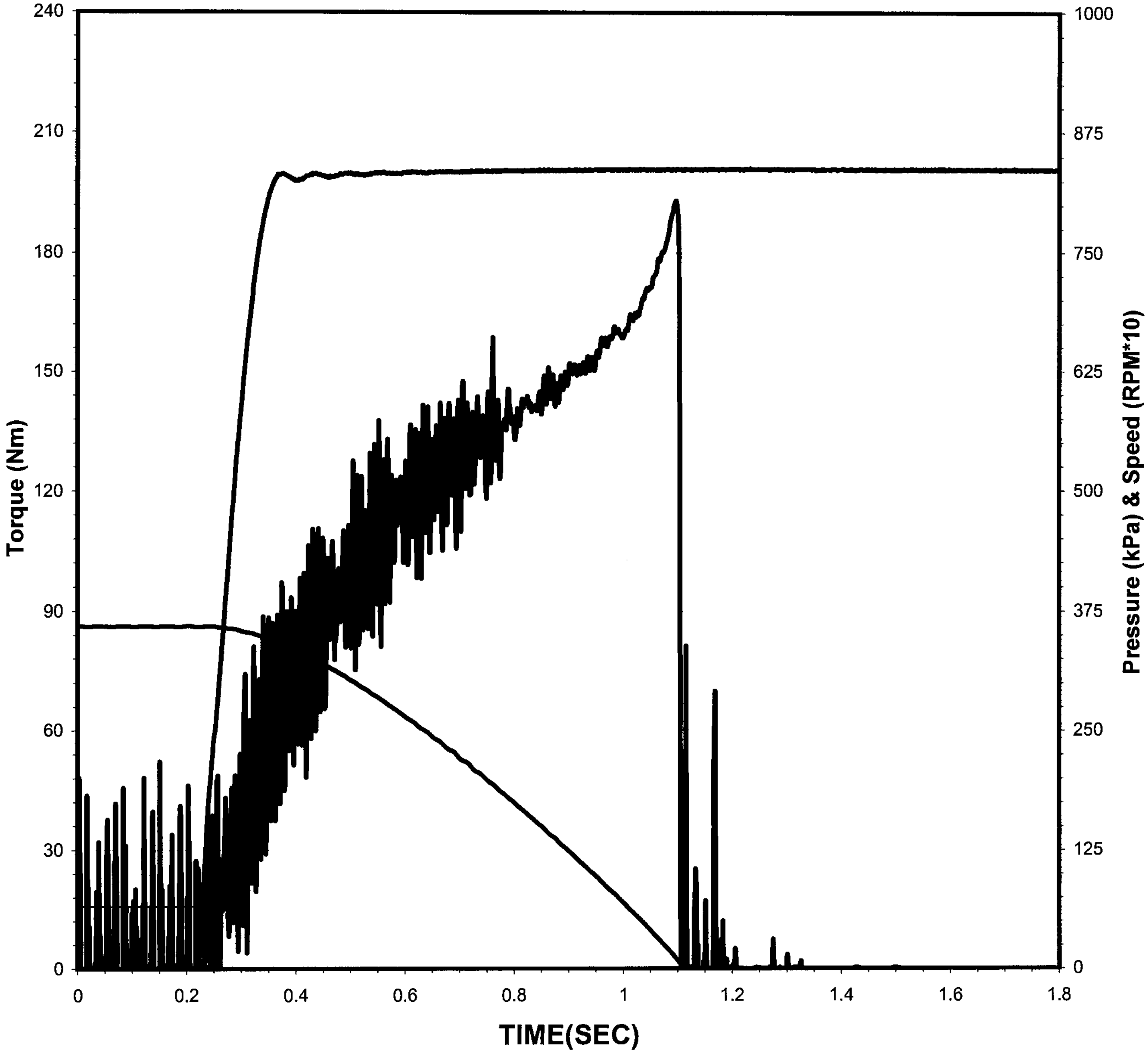
0.2 Sec Dyn:	**85 N*m**
Midpoint Dyn:	**121 N*m**
LwSpd Dynamic:	**187 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.059**
Midpoint Dyn:	**0.083**
LwSpd Dynamic:	**0.130**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/20/2010**
Time of Test:	**4:32:52**
Test Number:	**C4-6-1284**
Fluid Code:	**LO250033**
Cycle Number:	**3999**
Temperature:	**113.4 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**835 kPa** 827 ± 7 KPa)
Apply Rate:	**0.14 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.883 Sec**

Torque

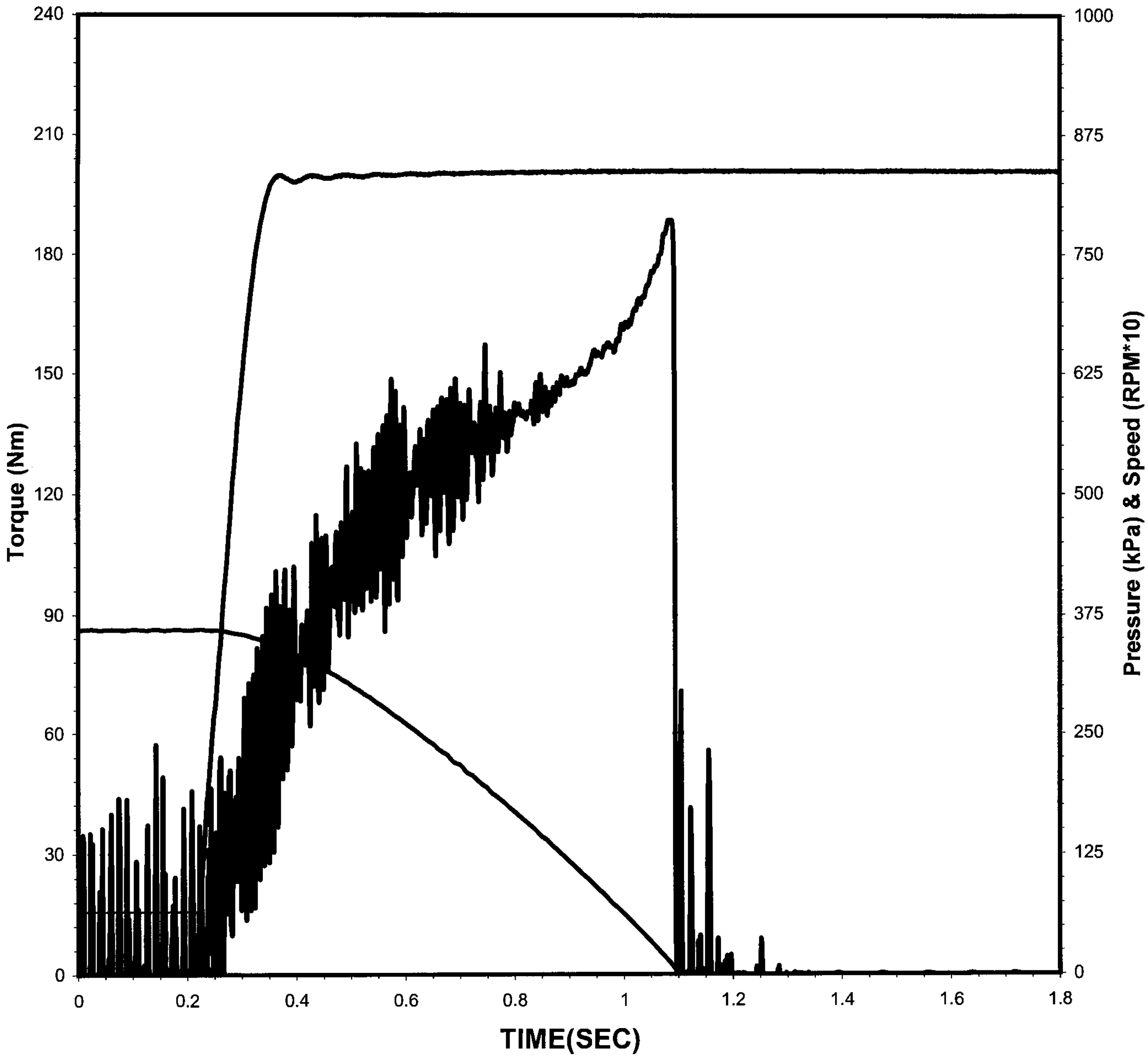
0.2 Sec Dyn:	**83 N*m**
Midpoint Dyn:	**125 N*m**
LwSpd Dynamic:	**189 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.057**
Midpoint Dyn:	**0.086**
LwSpd Dynamic:	**0.130**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	4:33:07
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	4000
Temperature:	113.3 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	835 kPa
	827 ± 7 KPa)
Apply Rate:	0.15 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.878 Sec

Torque

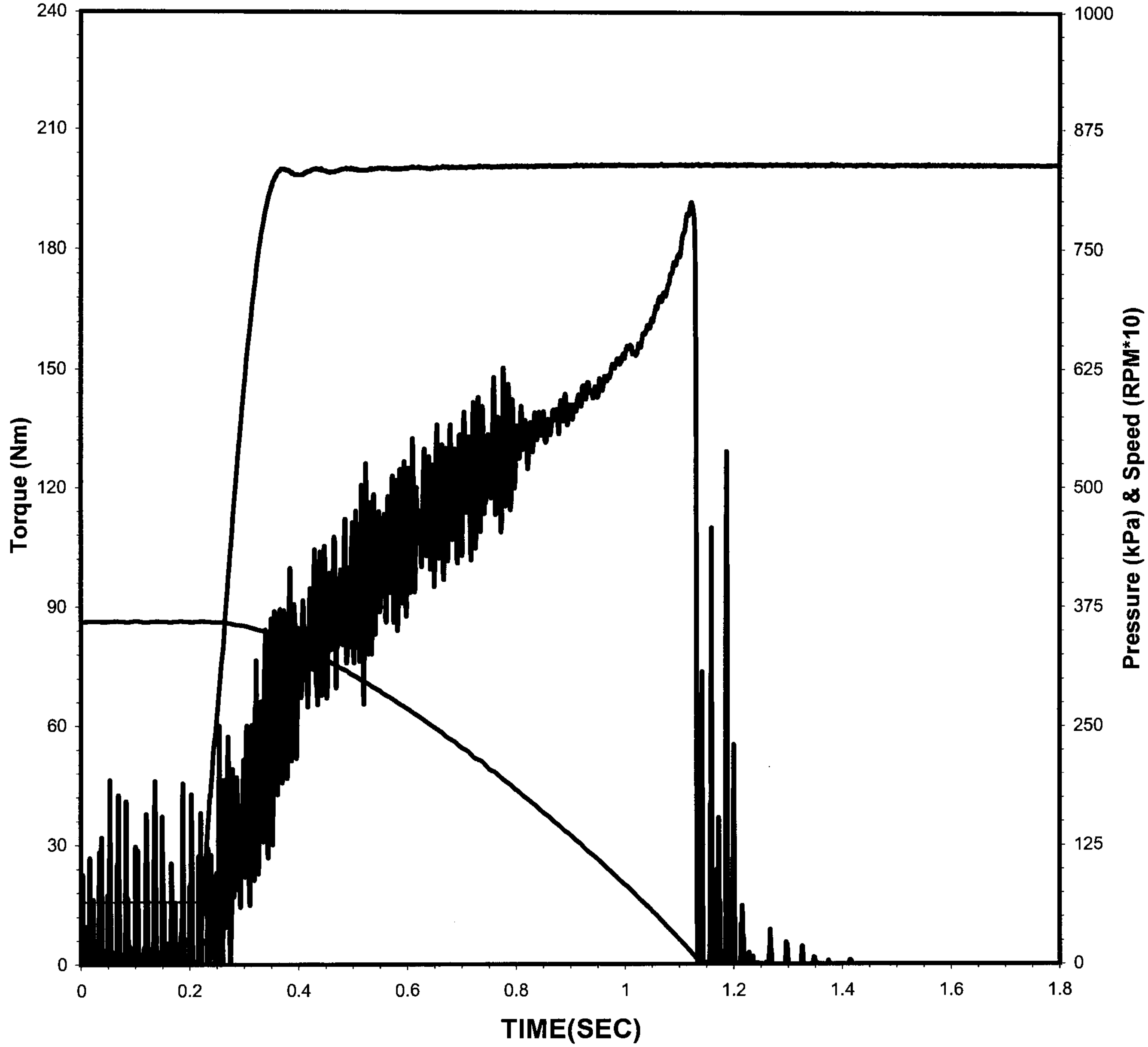
0.2 Sec Dyn:	82 N*m
Midpoint Dyn:	128 N*m
LwSpd Dynamic:	182 N*m

Coefficient of Friction

.2 Sec Dyn:	0.056
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	4:33:34
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	4001
Temperature:	109.2 °C (112.7 ± 3.0 °C)
Apply Pressure:	835 kPa 827 ± 7 KPa)
Apply Rate:	0.15 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.913 Sec

Torque

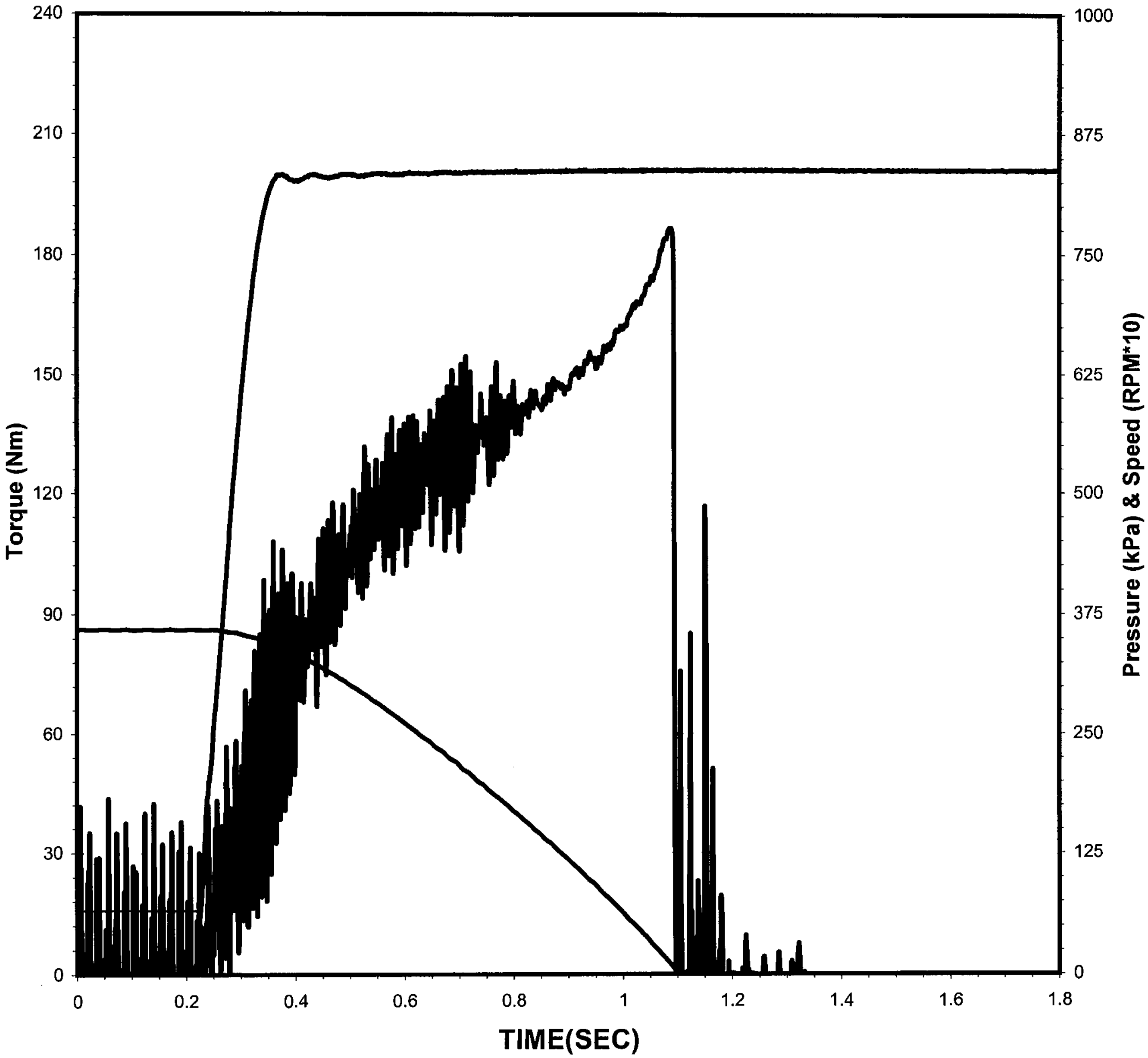
0.2 Sec Dyn:	82 N*m
Midpoint Dyn:	119 N*m
LwSpd Dynamic:	185 N*m

Coefficient of Friction

.2 Sec Dyn:	0.056
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/20/2010

Time of Test: 6:38:04

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 4499

Temperature: 113.4 °C
(112.7 ± 3.0 °C)

Apply Pressure: 835 kPa
827 ± 7 KPa)

Apply Rate: 0.14 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.875 Sec

Torque

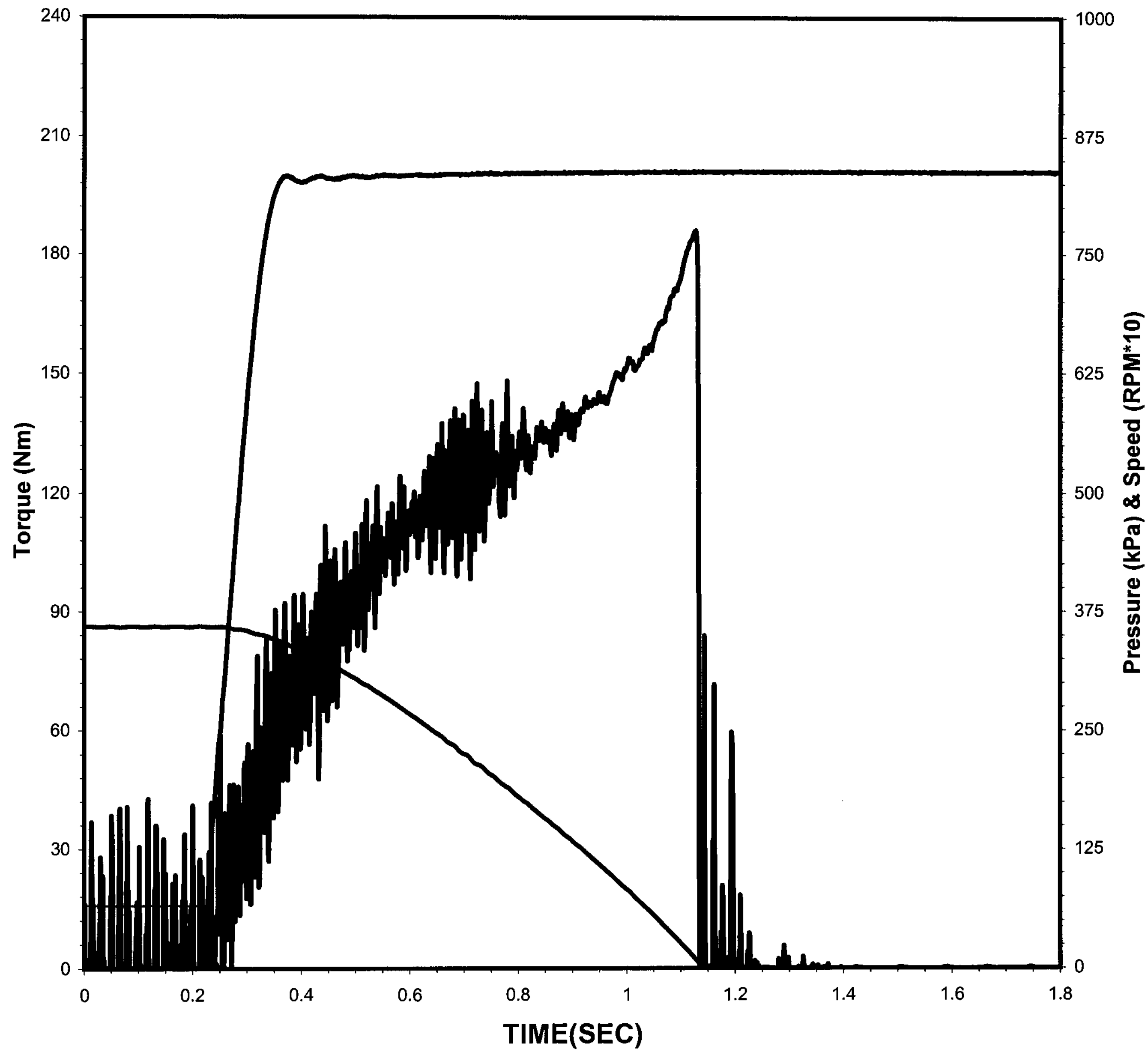
0.2 Sec Dyn:	83 N*m
Midpoint Dyn:	129 N*m
LwSpd Dynamic:	183 N*m

Coefficient of Friction

.2 Sec Dyn:	0.058
Midpoint Dyn:	0.089
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	6:38:19
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	4500
Temperature:	113.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	835 kPa 827 ± 7 KPa)
Apply Rate:	0.15 Sec (0.15 ± 0.02 Sec)
Energy:	18.3 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.912 Sec

Torque

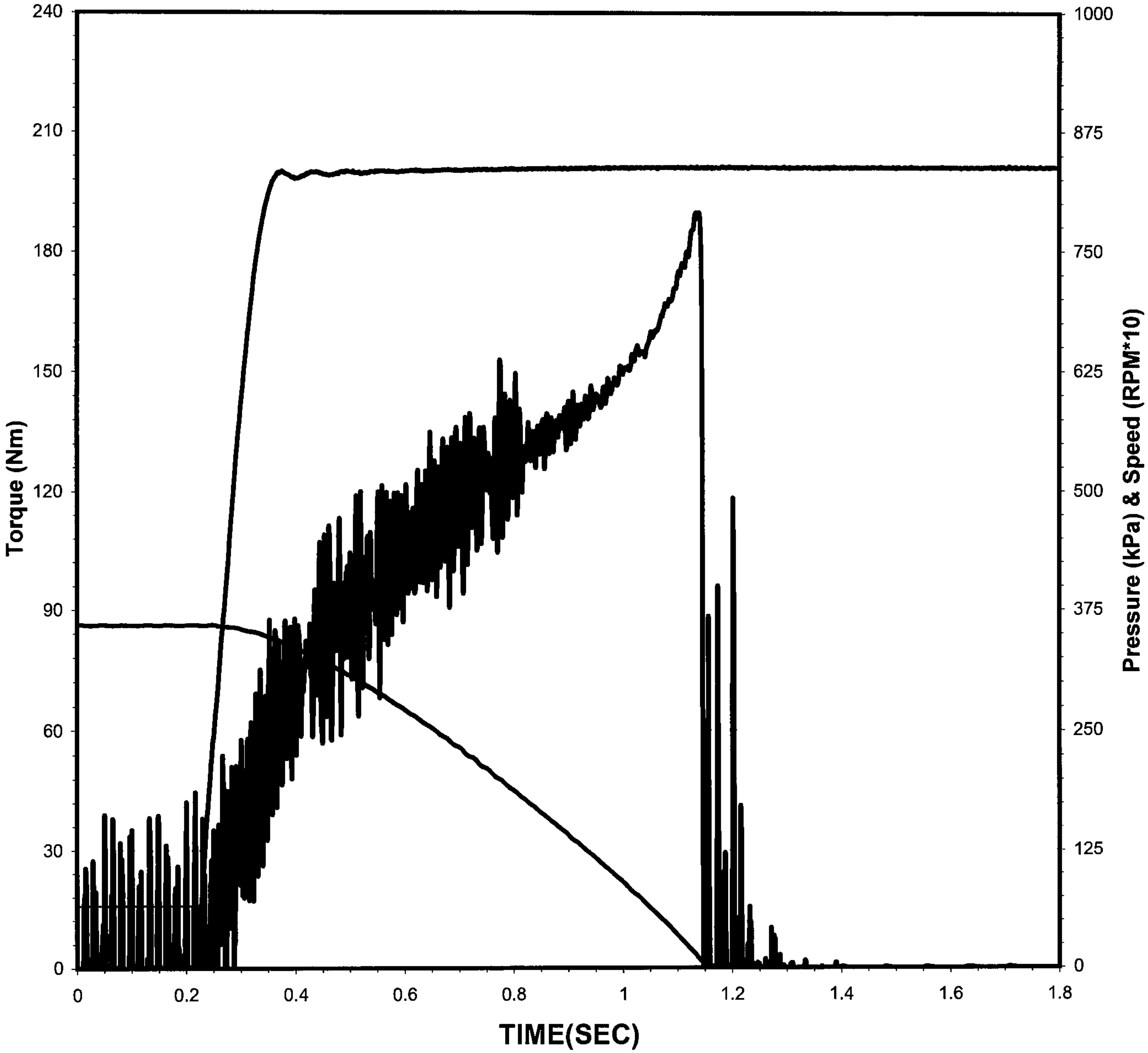
0.2 Sec Dyn:	79 N*m
Midpoint Dyn:	121 N*m
LwSpd Dynamic:	184 N*m

Coefficient of Friction

.2 Sec Dyn:	0.055
Midpoint Dyn:	0.084
LwSpd Dynamic:	0.127

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	6:38:45
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	4501
Temperature:	109.1 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	835 kPa
	827 ± 7 KPa)
Apply Rate:	0.15 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.3 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.925 Sec

Torque

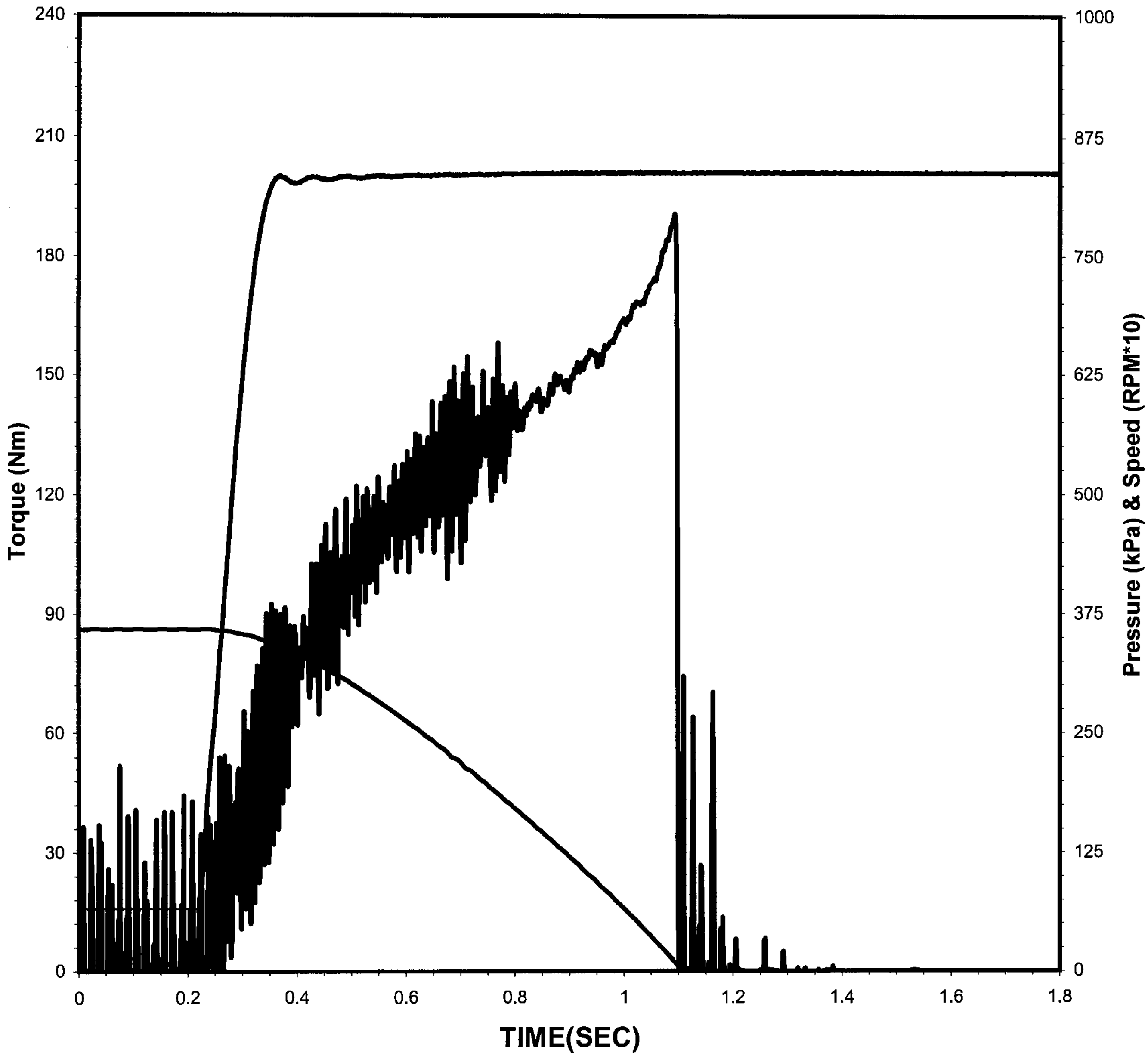
0.2 Sec Dyn:	77 N*m
Midpoint Dyn:	117 N*m
LwSpd Dynamic:	185 N*m

Coefficient of Friction

.2 Sec Dyn:	0.053
Midpoint Dyn:	0.081
LwSpd Dynamic:	0.128

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	8:43:15
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	4999
Temperature:	113.3 °C (112.7 ± 3.0 °C)
Apply Pressure:	835 kPa 827 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.882 Sec

Torque

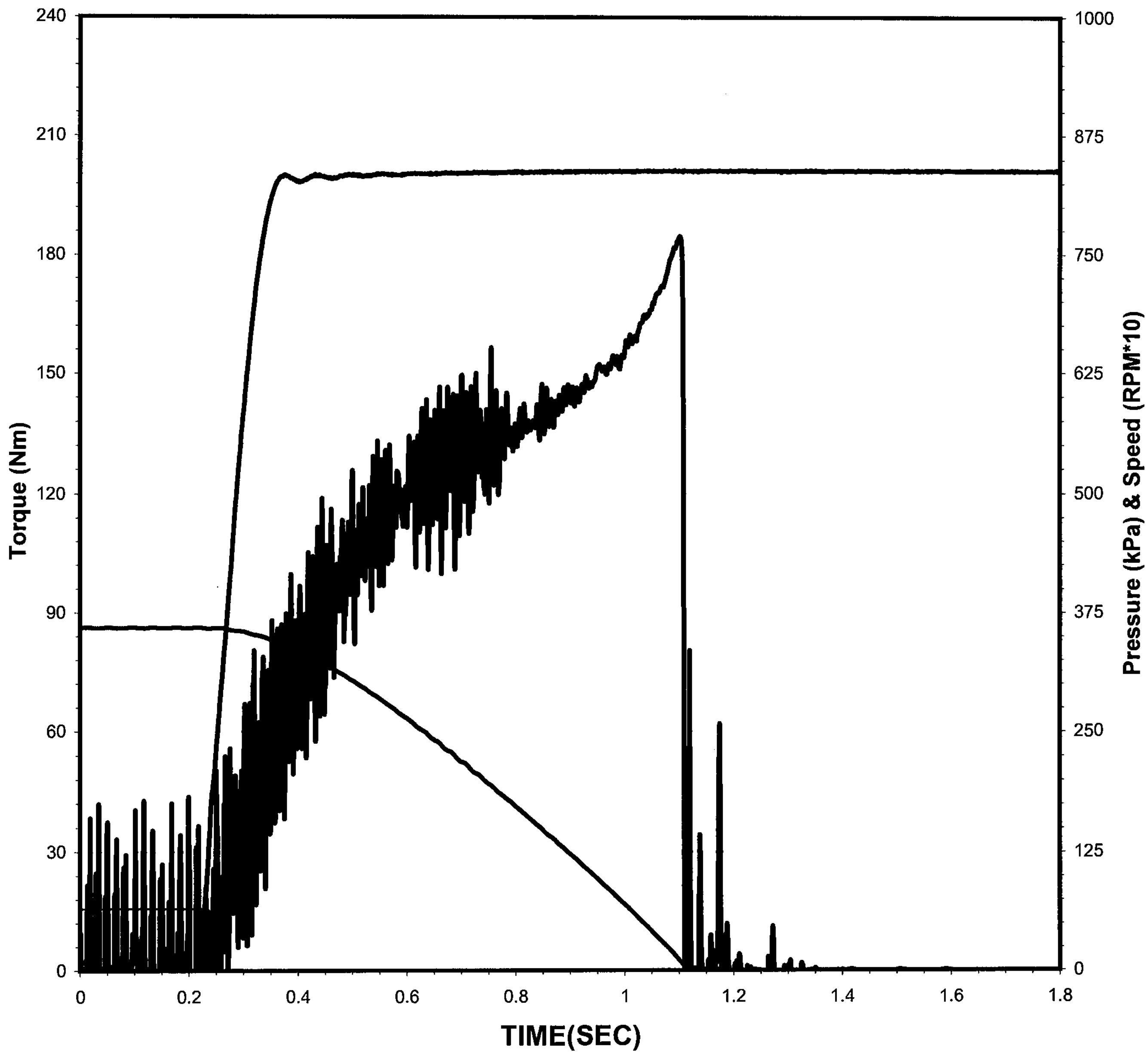
0.2 Sec Dyn:	84 N*m
Midpoint Dyn:	126 N*m
LwSpd Dynamic:	188 N*m

Coefficient of Friction

.2 Sec Dyn:	0.058
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.130

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	8:43:31
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	5000
Temperature:	112.9 °C (112.7 ± 3.0 °C)
Apply Pressure:	835 kPa 827 ± 7 KPa)
Apply Rate:	0.15 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.886 Sec

Torque

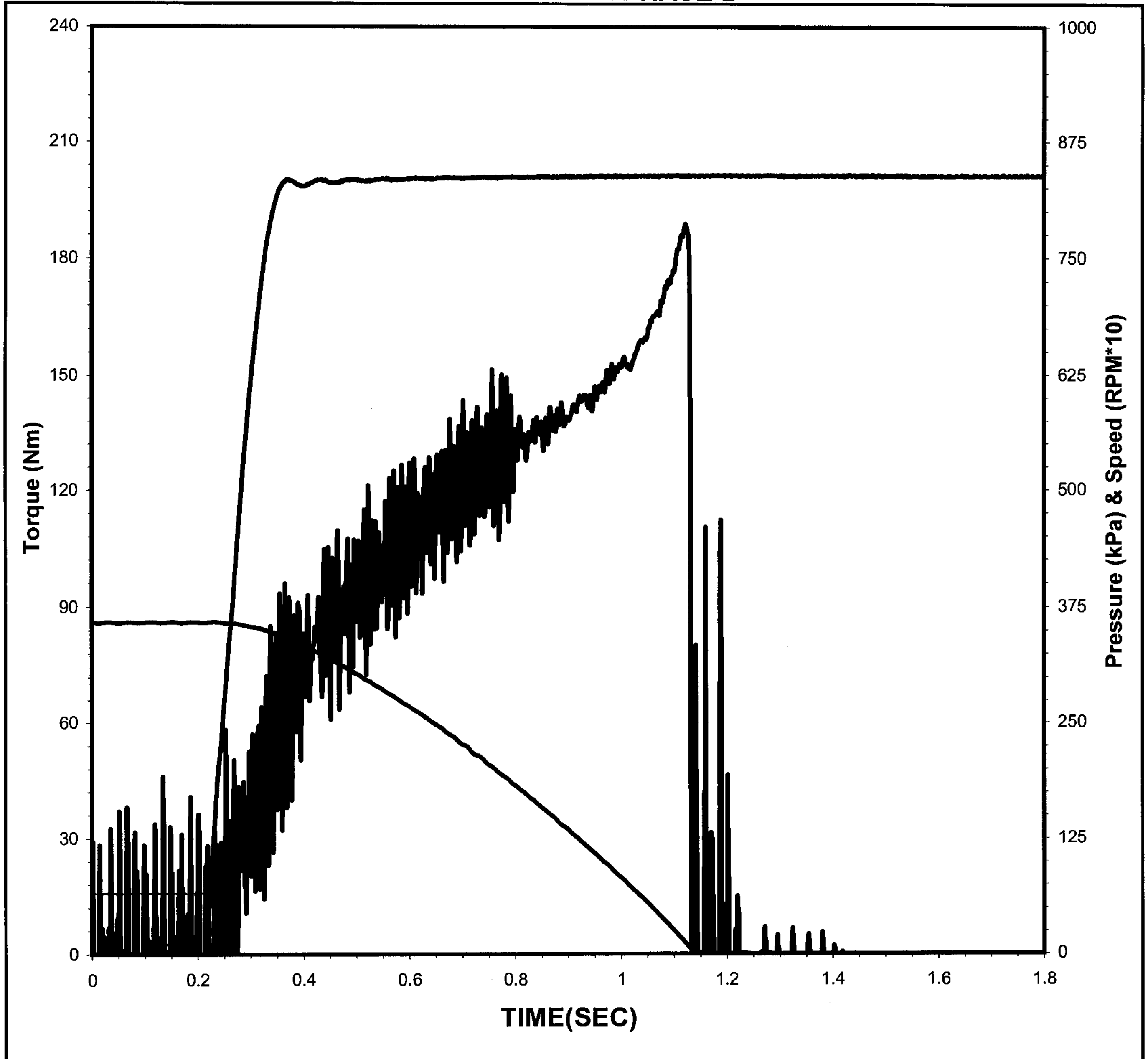
0.2 Sec Dyn:	84 N*m
Midpoint Dyn:	127 N*m
LwSpd Dynamic:	182 N*m

Coefficient of Friction

.2 Sec Dyn:	0.058
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.126

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/20/2010

Time of Test: 8:43:57

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 5001

Temperature: 108.8 °C
(112.7 ± 3.0 °C)

Apply Pressure: 836 kPa
827 ± 7 KPa)

Apply Rate: 0.15 Sec
(0.15 ± 0.02 Sec)

Energy: 18.3 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.914 Sec

Torque

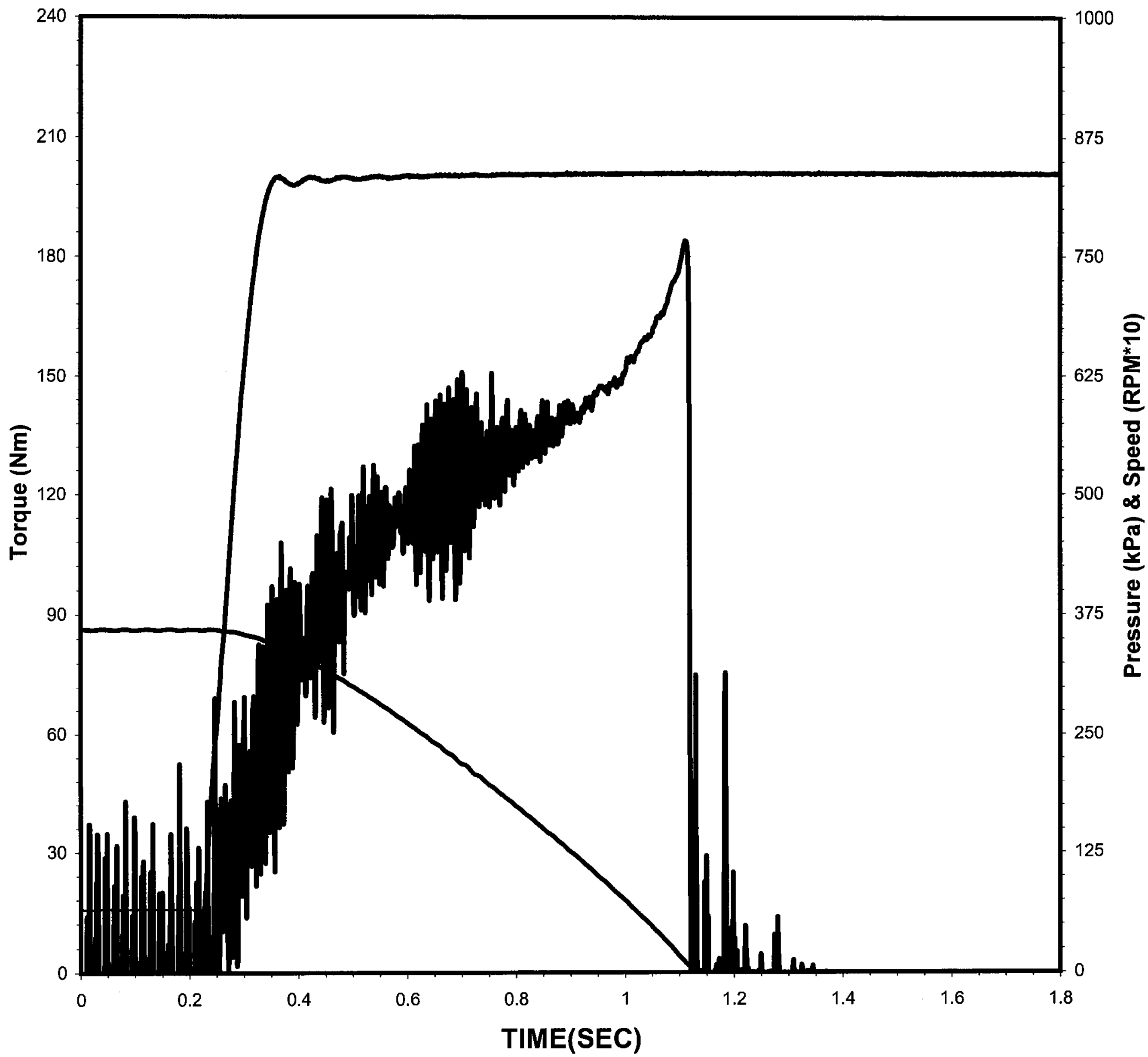
0.2 Sec Dyn:	80 N*m
Midpoint Dyn:	119 N*m
LwSpd Dynamic:	181 N*m

Coefficient of Friction

.2 Sec Dyn:	0.056
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	10:48:12
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	5498
Temperature:	113.4 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	835 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.897 Sec

Torque

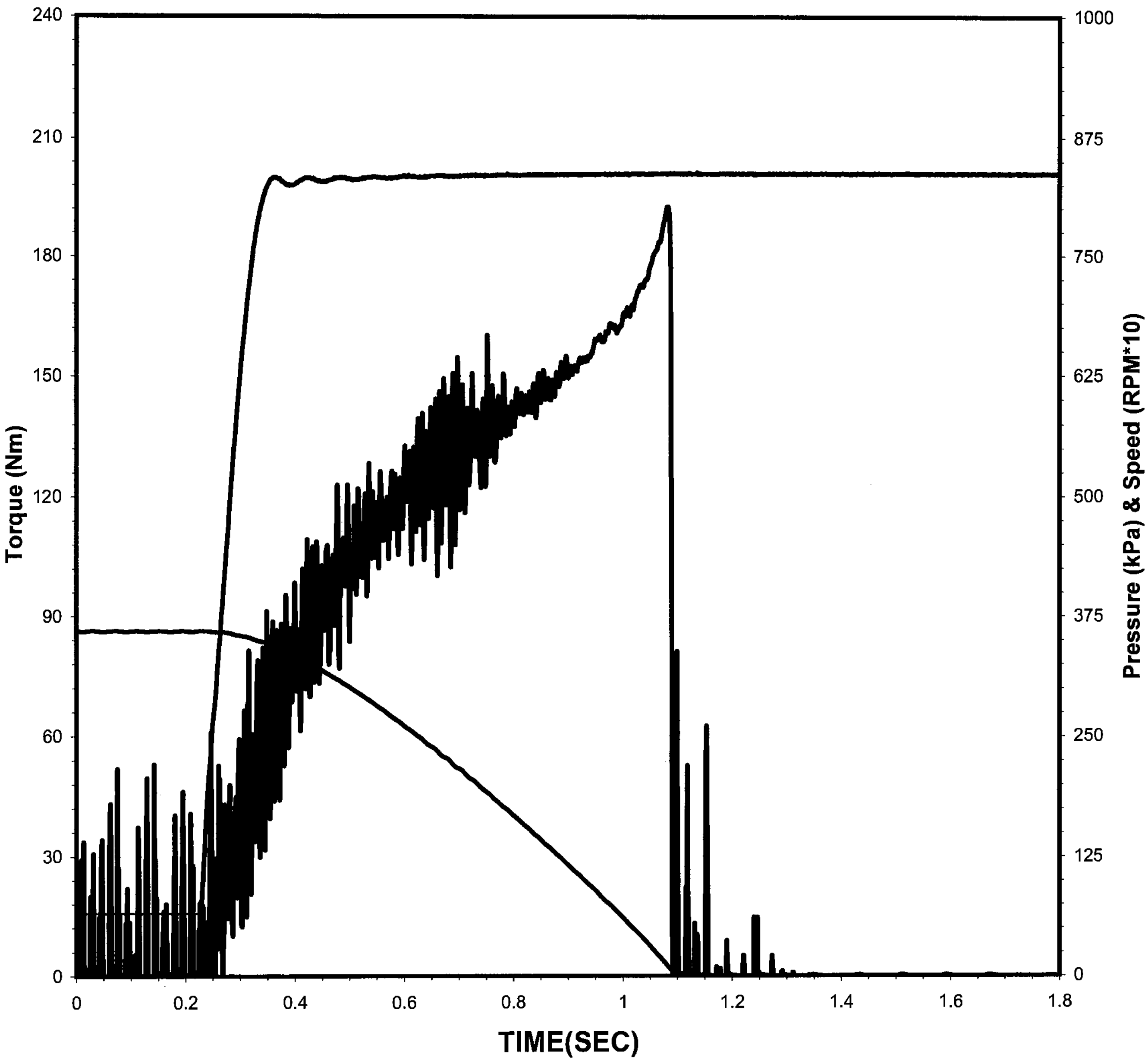
0.2 Sec Dyn:	86 N*m
Midpoint Dyn:	123 N*m
LwSpd Dynamic:	181 N*m

Coefficient of Friction

.2 Sec Dyn:	0.060
Midpoint Dyn:	0.085
LwSpd Dynamic:	0.125

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	10:48:27
Test Number:	C4-6-1284
Fluid Code:	LO250033
Cycle Number:	5499
Temperature:	113.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	835 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.868 Sec

Torque

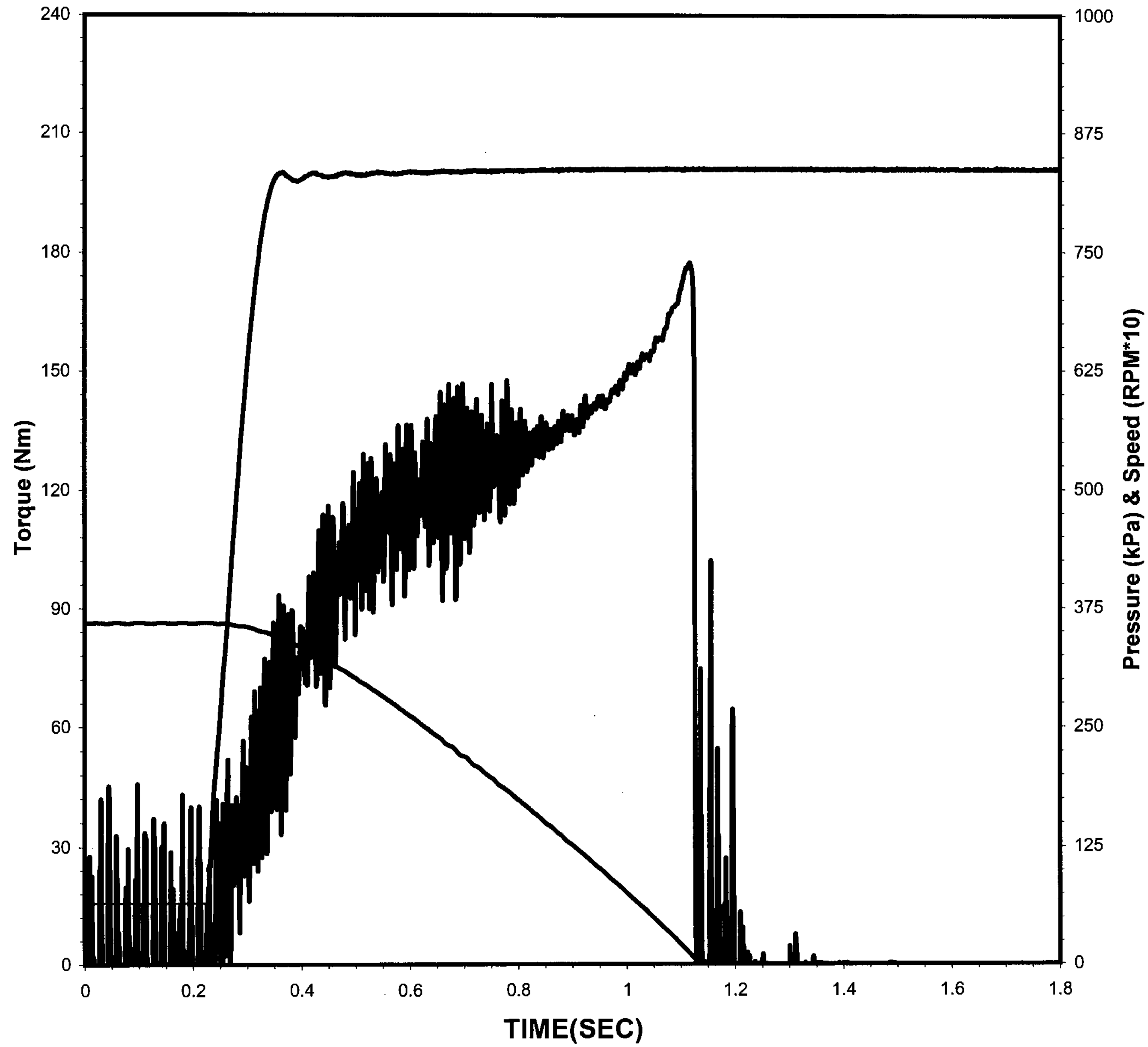
0.2 Sec Dyn:	87 N*m
Midpoint Dyn:	128 N*m
LwSpd Dynamic:	187 N*m

Coefficient of Friction

.2 Sec Dyn:	0.060
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.129

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/20/2010

Time of Test: 10:48:42

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 5500

Temperature: 113.3 °C
(112.7 ± 3.0 °C)

Apply Pressure: 835 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.904 Sec

Torque

0.2 Sec Dyn:	86 N*m
Midpoint Dyn:	122 N*m
LwSpd Dynamic:	172 N*m

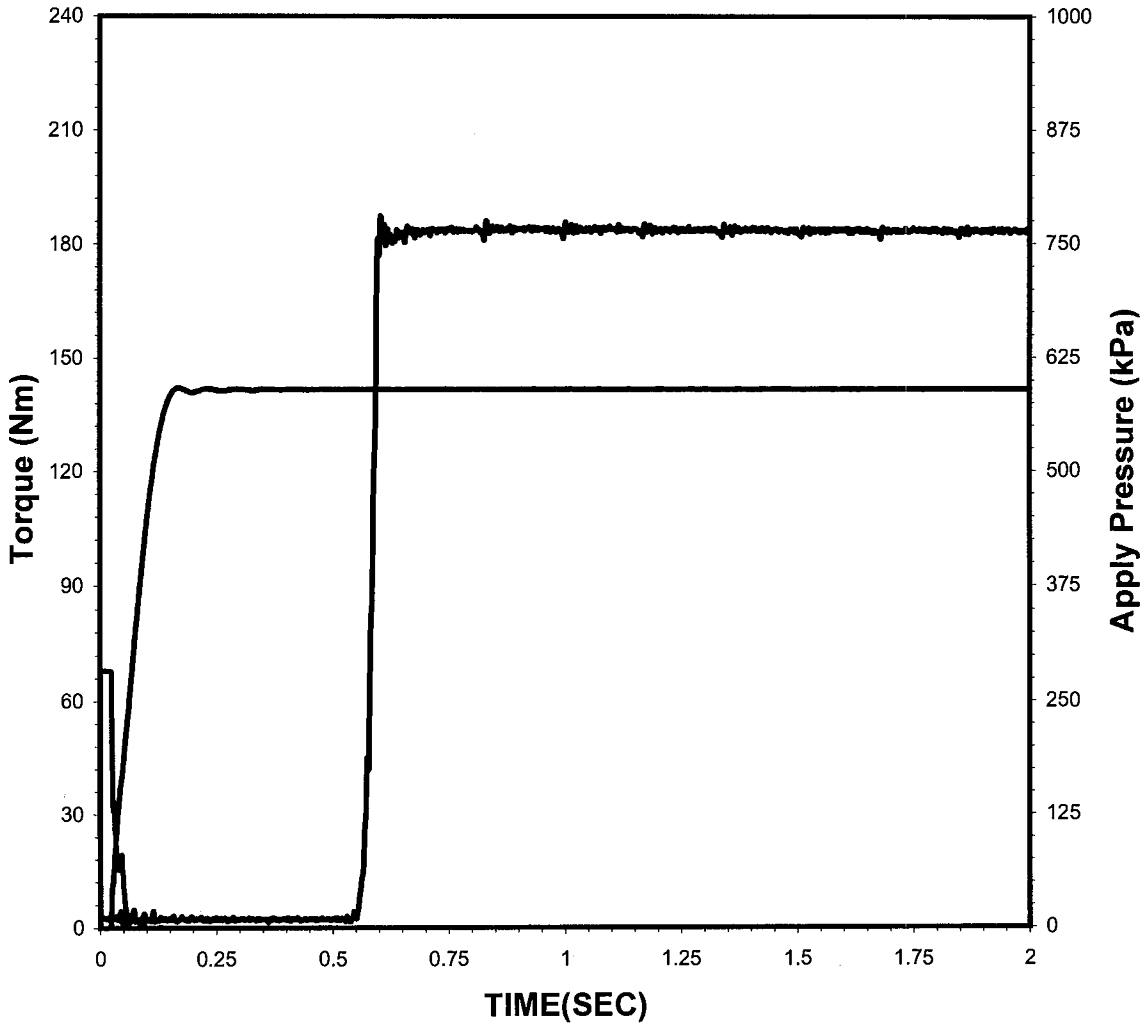
Coefficient of Friction

.2 Sec Dyn:	0.060
Midpoint Dyn:	0.085
LwSpd Dynamic:	0.119

STATIC TRACES

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/19/2010

Time of Test: 11:48:02

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 10

PHASE A

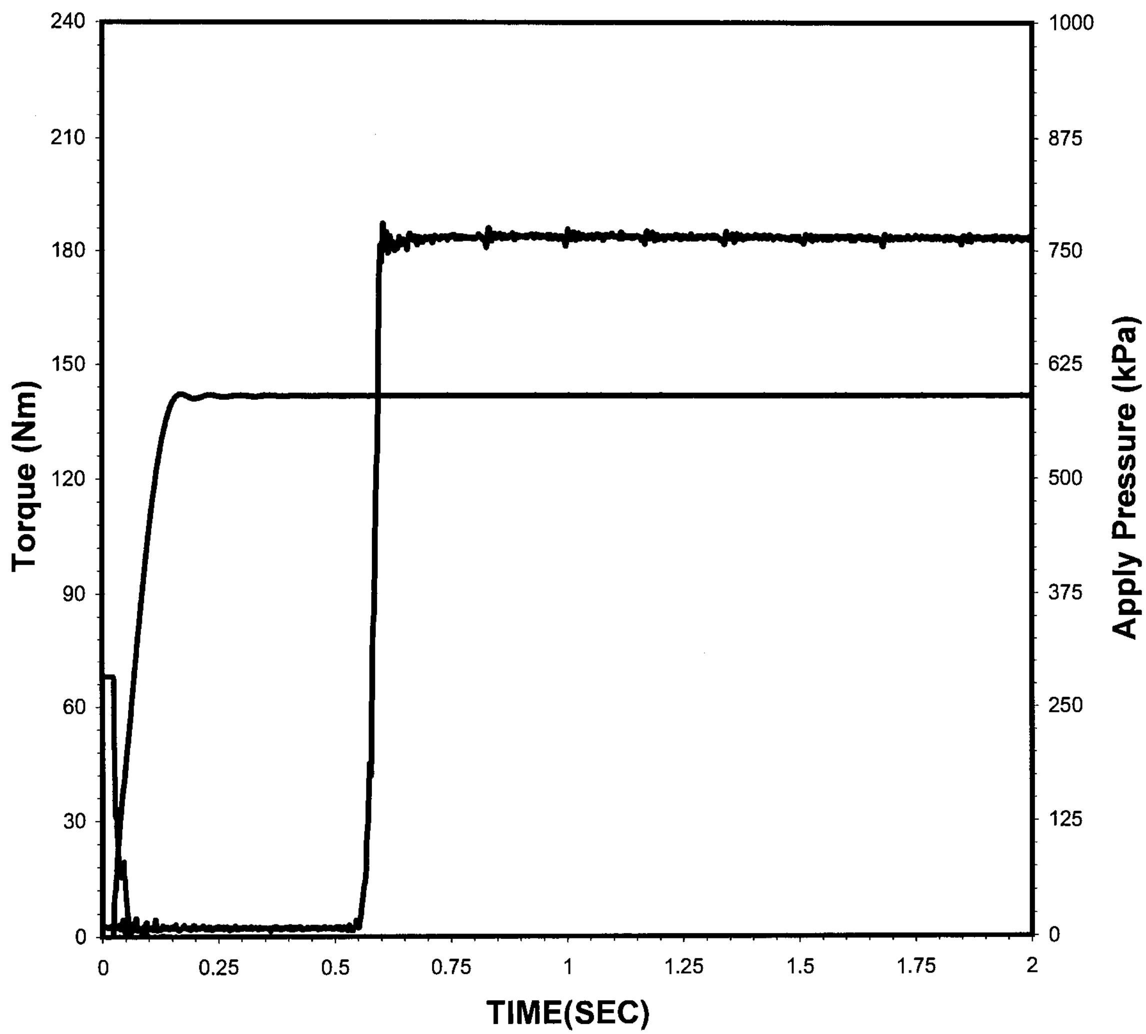
Apply Pressure:
At .25 Second: 347 kPa

Torque
Static Peak: 126 Nm
.25 Second: 95 Nm

Coefficient of Friction
Static Peak: 0.208
.25 Second: 0.157

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/19/2010

Time of Test: 13:50:43

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 500

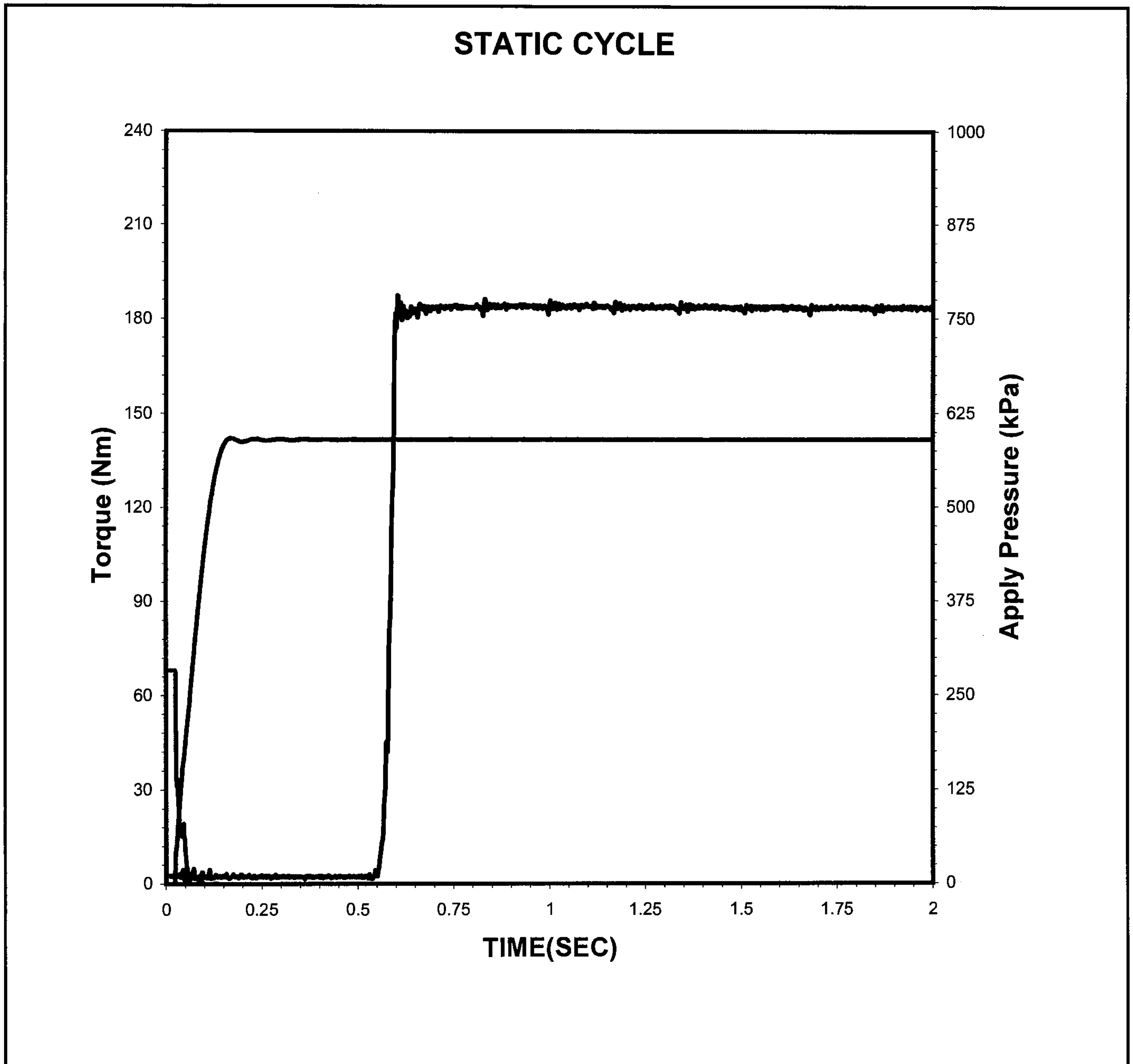
PHASE A

Apply Pressure:
At .25 Second: 349 kPa

Torque
Static Peak: 122 Nm
.25 Second: 95 Nm

Coefficient of Friction
Static Peak: 0.202
.25 Second: 0.157

ALLISON C-4 GRAPHITE DATA



Date of Test: 7/19/2010

Time of Test: 15:55:55

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 1000

PHASE A

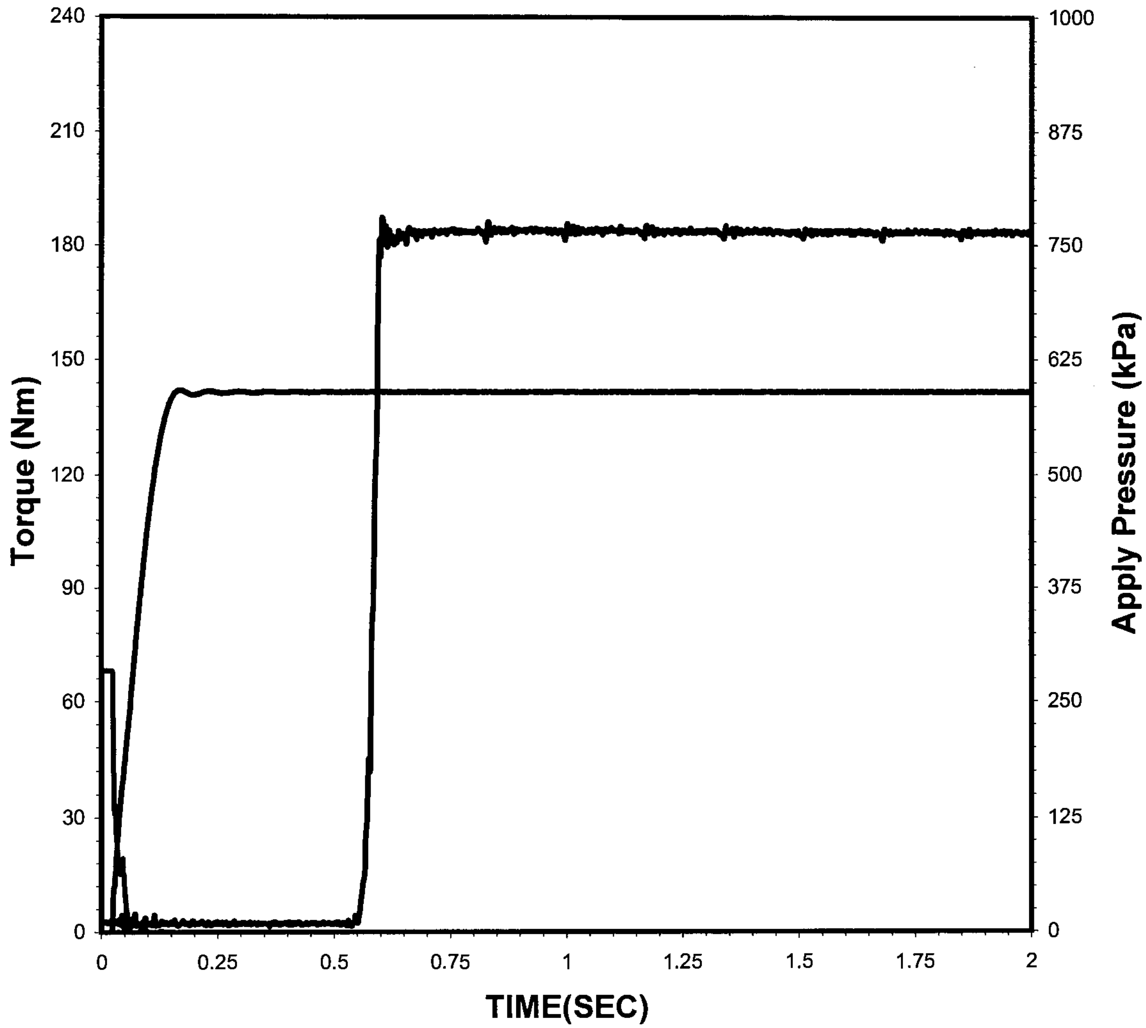
Apply Pressure:
At .25 Second: 349 kPa

Torque
Static Peak: 117 Nm
.25 Second: 93 Nm

Coefficient of Friction
Static Peak: 0.195
.25 Second: 0.155

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/19/2010

Time of Test: 18:07:19

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 1500

PHASE B

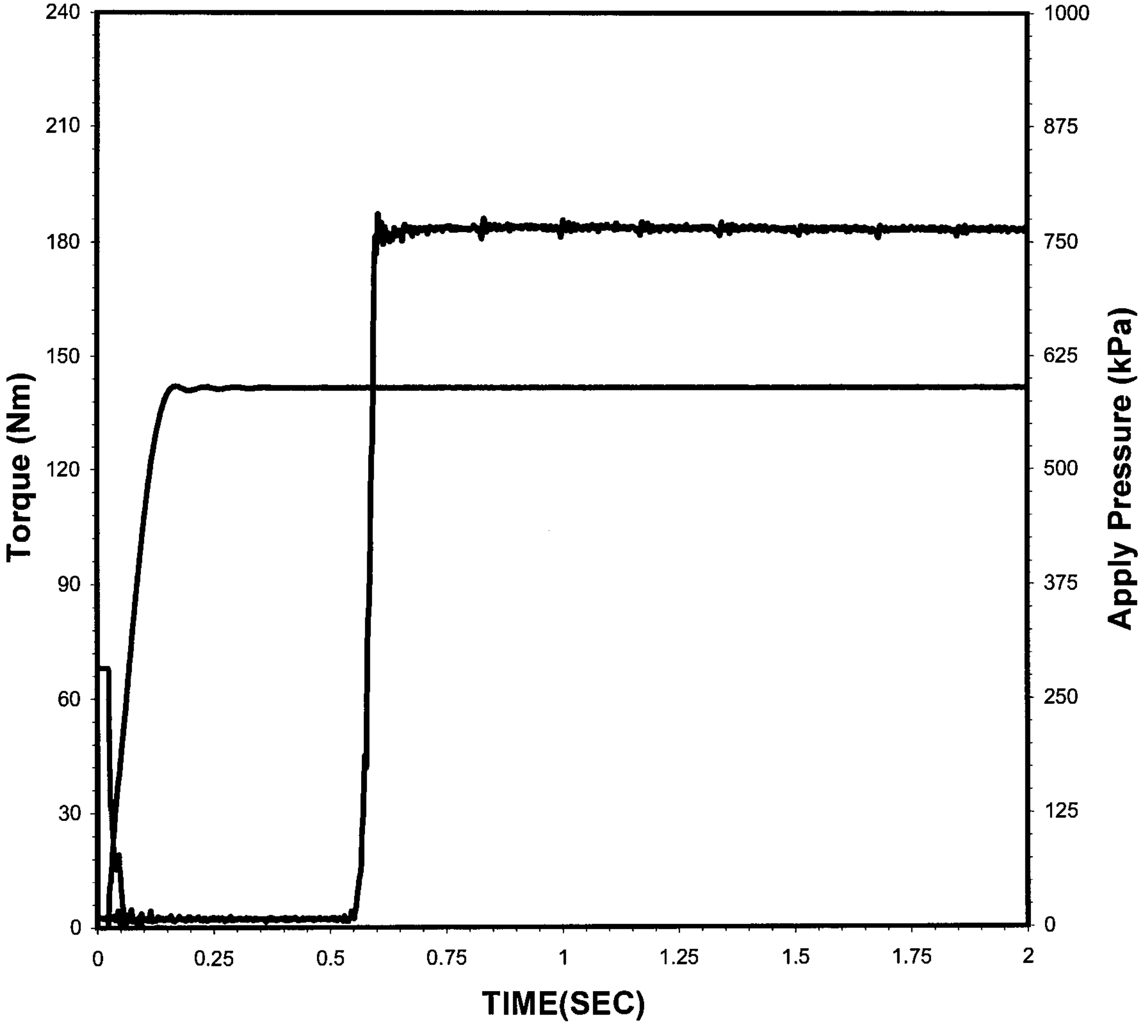
Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 218 Nm
.25 Second: 207 Nm

Coefficient of Friction
Static Peak: 0.151
.25 Second: 0.143

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/19/2010

Time of Test: 20:12:31

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 2000

PHASE B

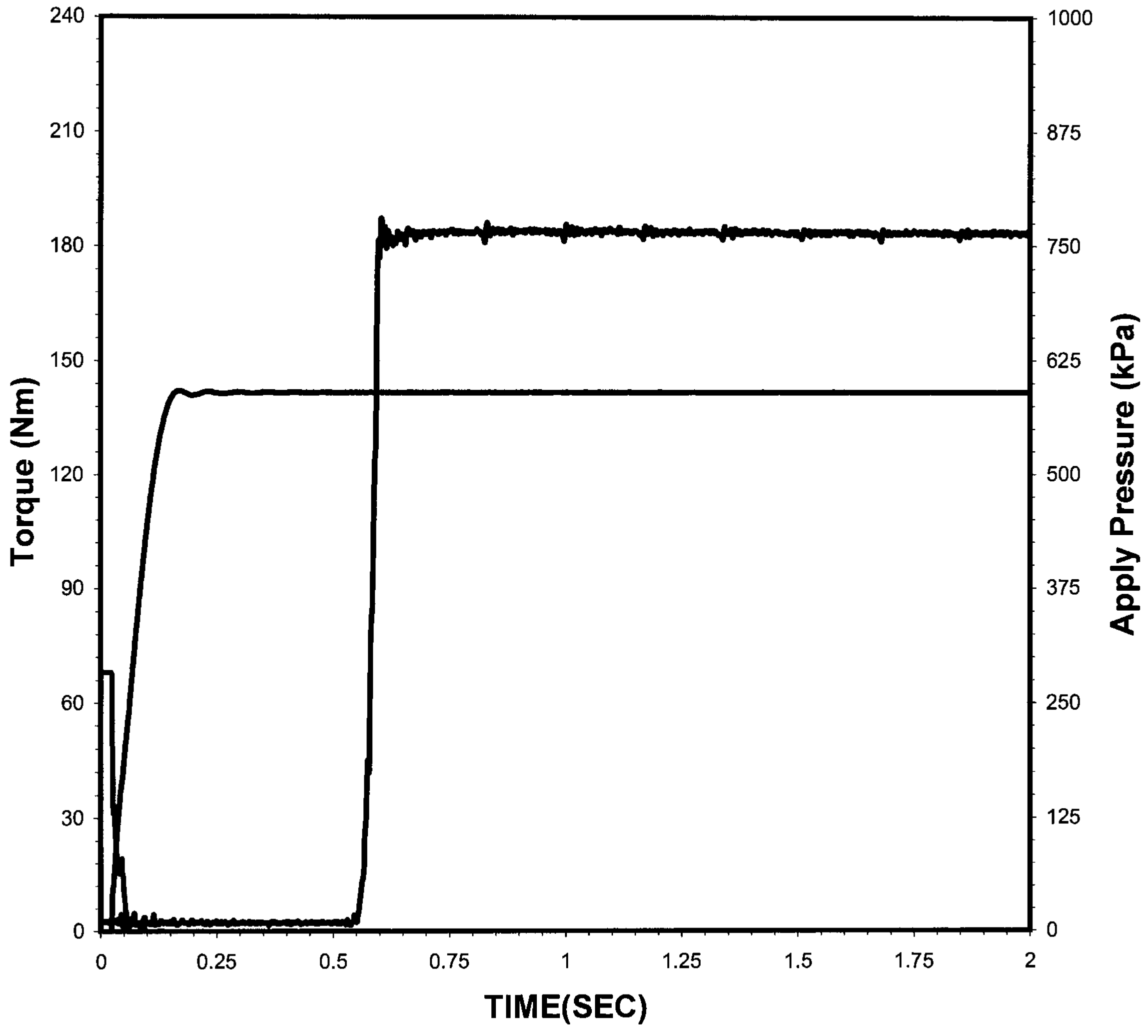
Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 211 Nm
.25 Second: 204 Nm

Coefficient of Friction
Static Peak: 0.146
.25 Second: 0.141

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/19/2010

Time of Test: 22:17:43

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 2500

PHASE B

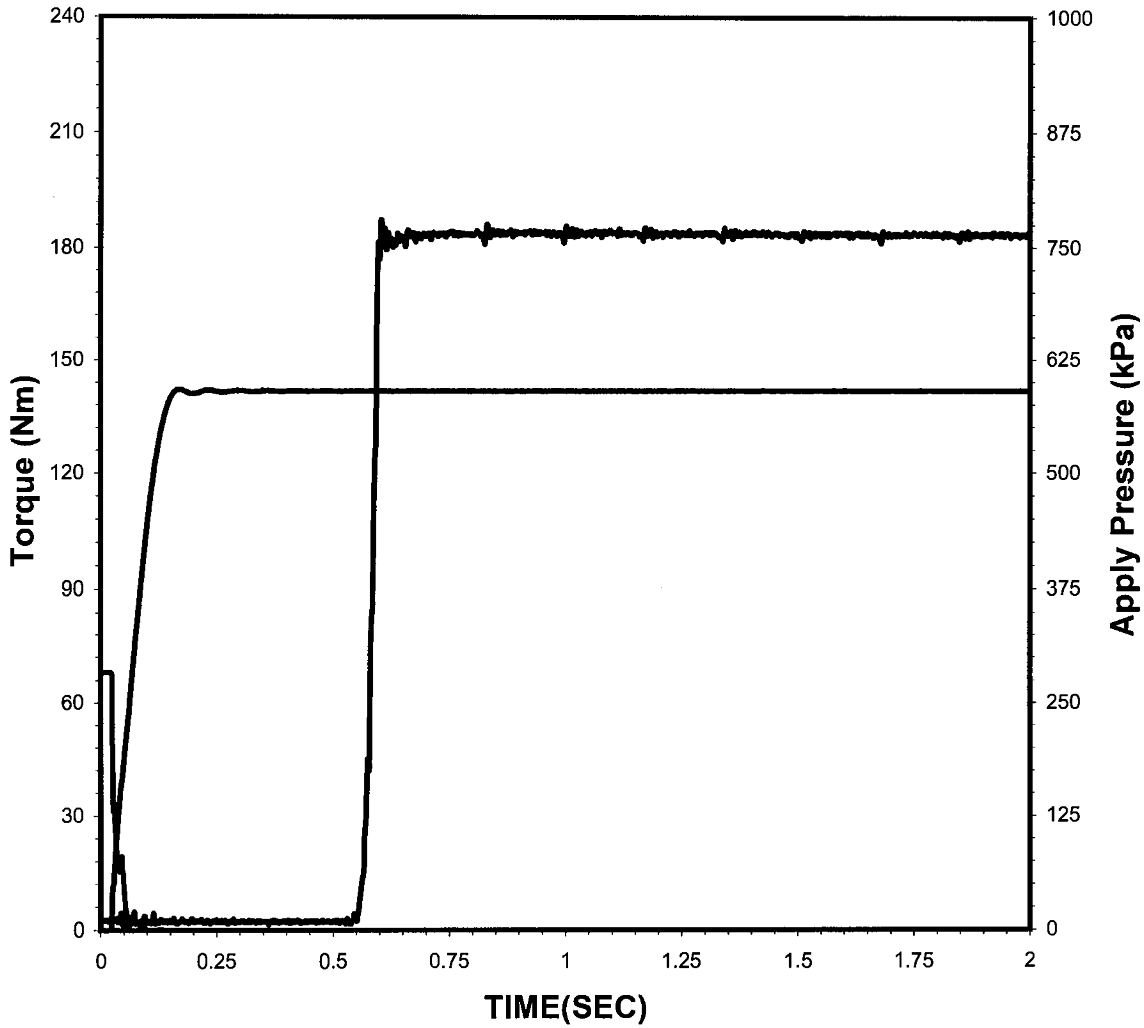
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 214 Nm
.25 Second: 203 Nm

Coefficient of Friction
Static Peak: 0.148
.25 Second: 0.140

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 0:22:55

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 3000

PHASE B

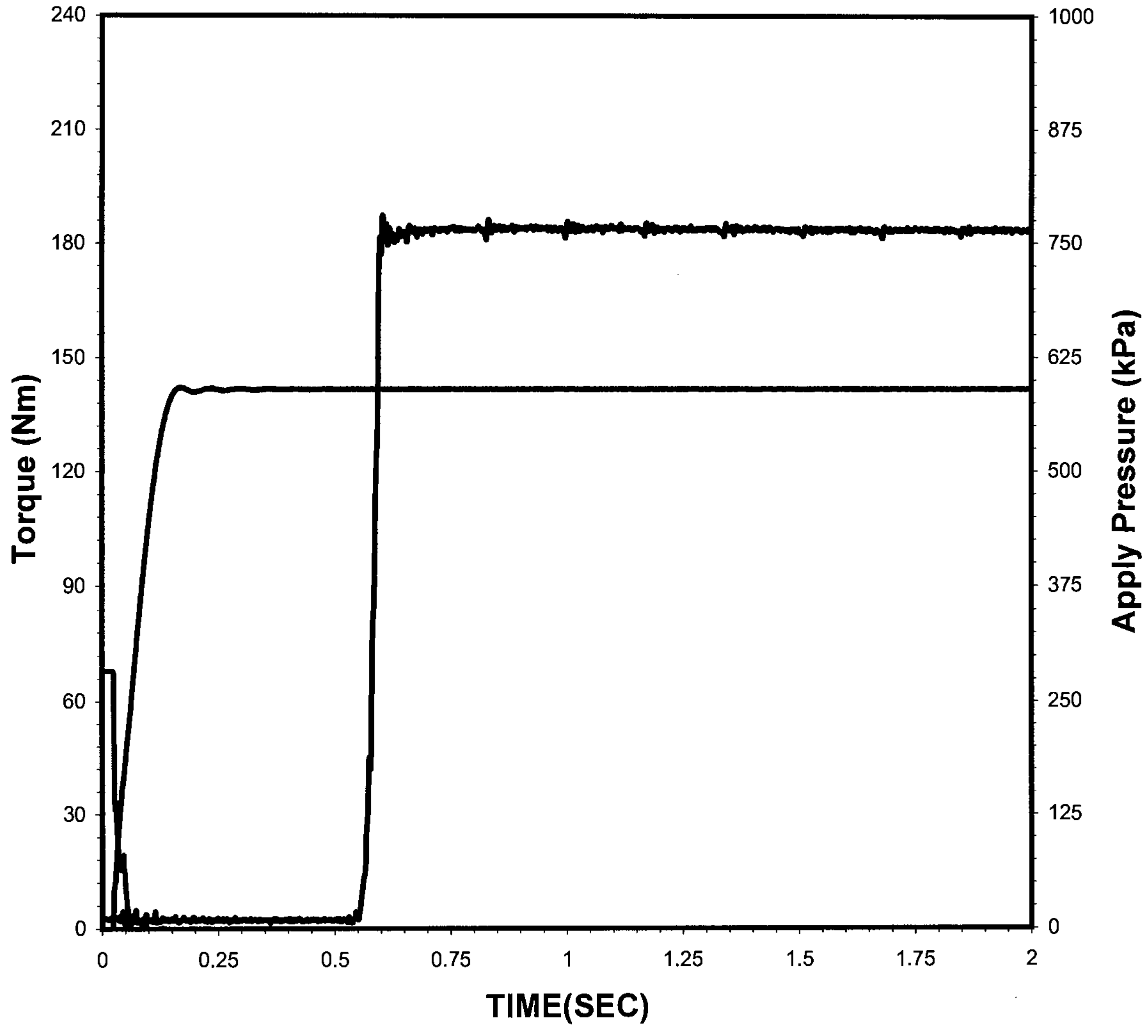
Apply Pressure:
At .25 Second: 834 kPa

Torque
Static Peak: 208 Nm
.25 Second: 202 Nm

Coefficient of Friction
Static Peak: 0.144
.25 Second: 0.139

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 2:28:07

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 3500

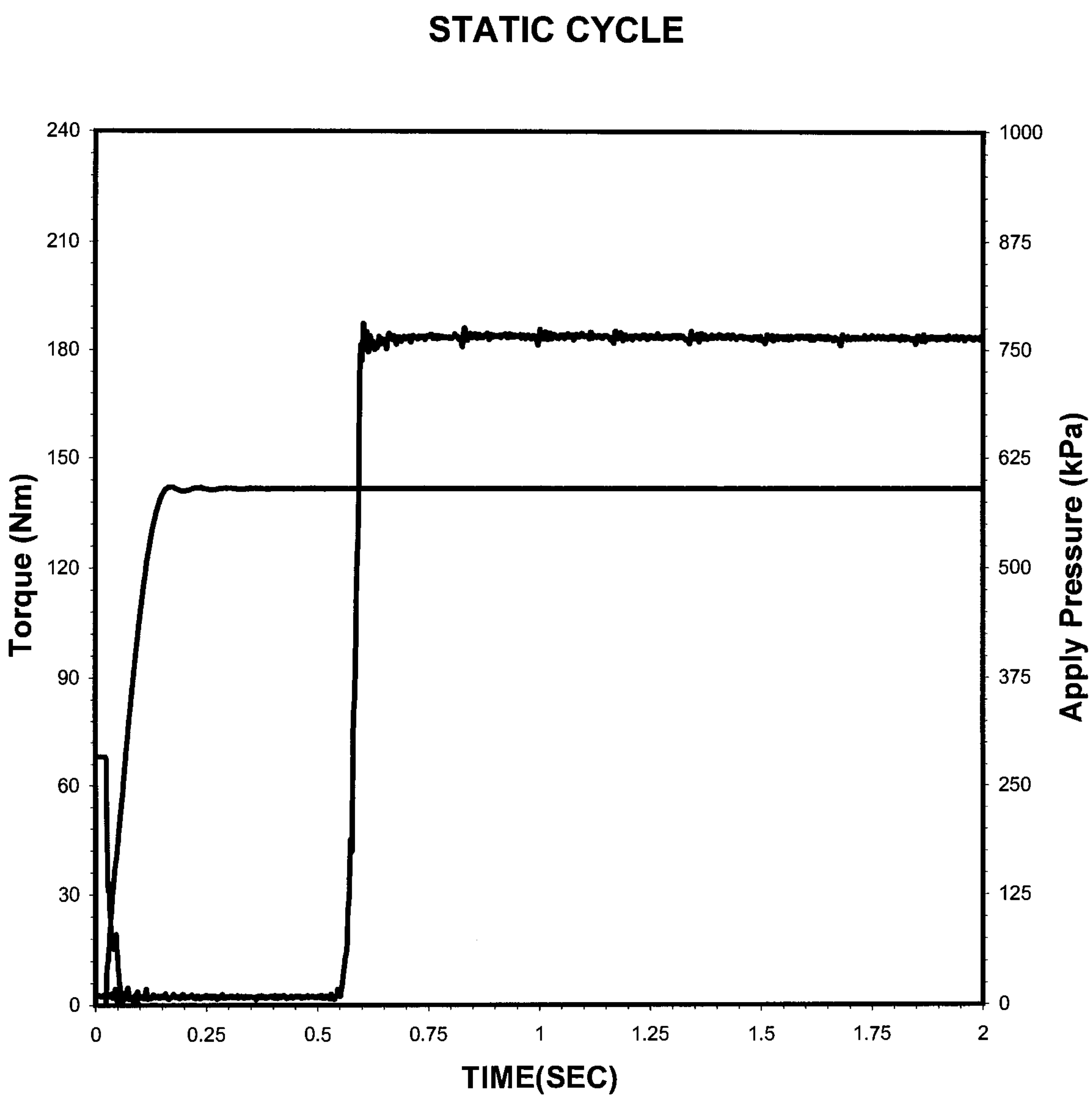
PHASE B

Apply Pressure:
At .25 Second: 835 kPa

Torque
Static Peak: 213 Nm
.25 Second: 200 Nm

Coefficient of Friction
Static Peak: 0.147
.25 Second: 0.138

ALLISON C-4 GRAPHITE DATA



Date of Test: 7/20/2010

Time of Test: 4:33:18

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 4000

PHASE B

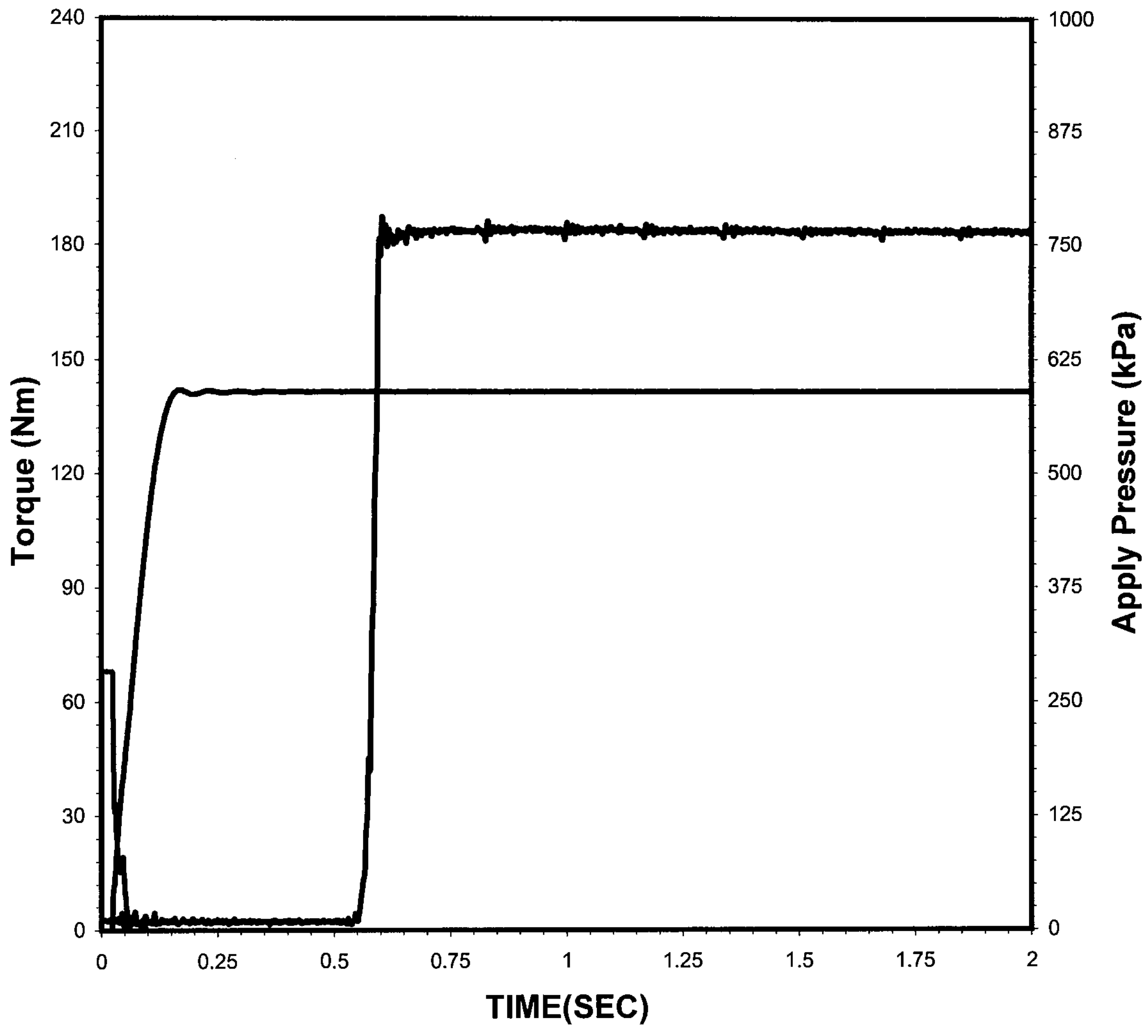
Apply Pressure:
At .25 Second: 835 kPa

Torque
Static Peak: 209 Nm
.25 Second: 200 Nm

Coefficient of Friction
Static Peak: 0.144
.25 Second: 0.138

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 6:38:30

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 4500

PHASE B

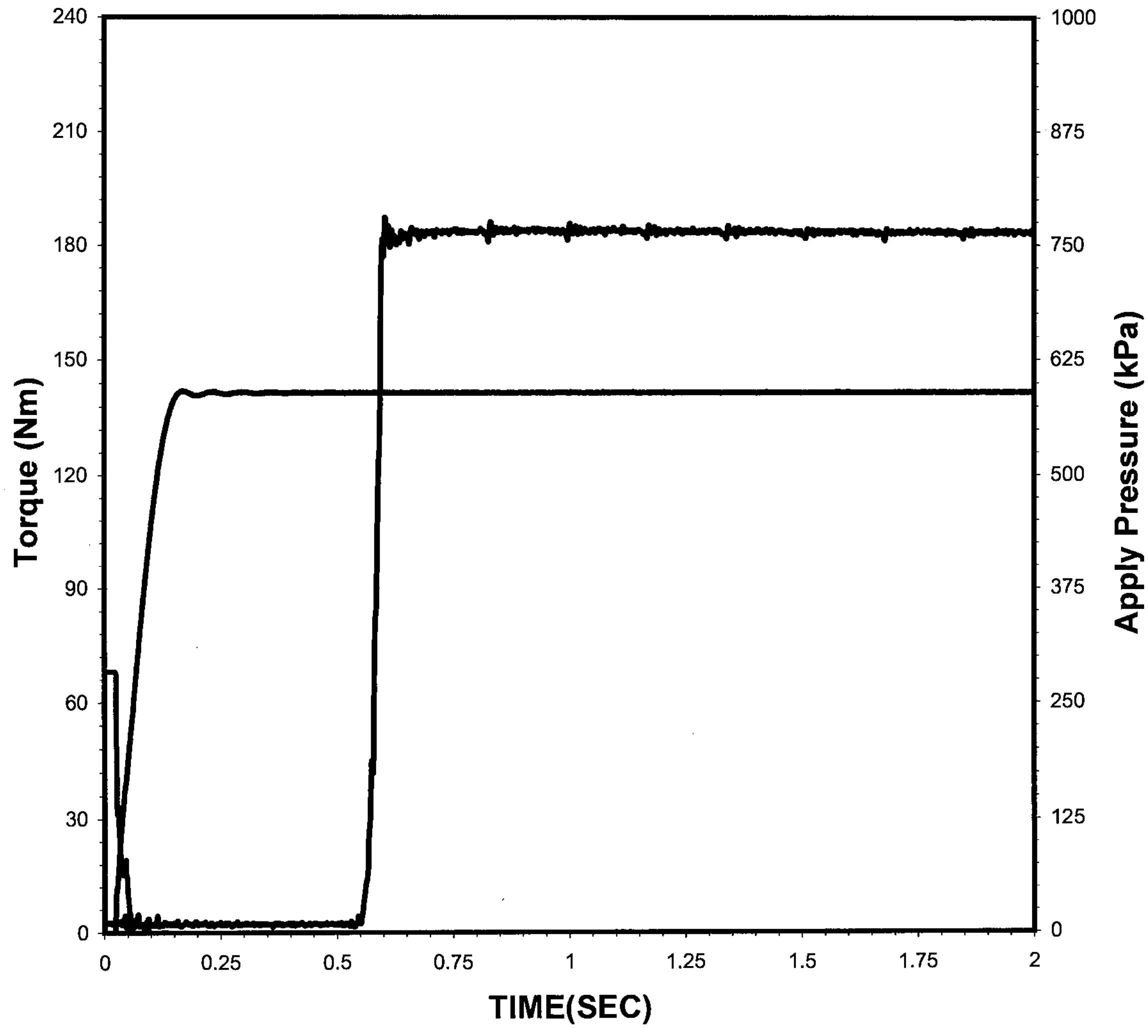
Apply Pressure:
At .25 Second: 835 kPa

Torque
Static Peak: 207 Nm
.25 Second: 200 Nm

Coefficient of Friction
Static Peak: 0.143
.25 Second: 0.138

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 8:43:42

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 5000

PHASE B

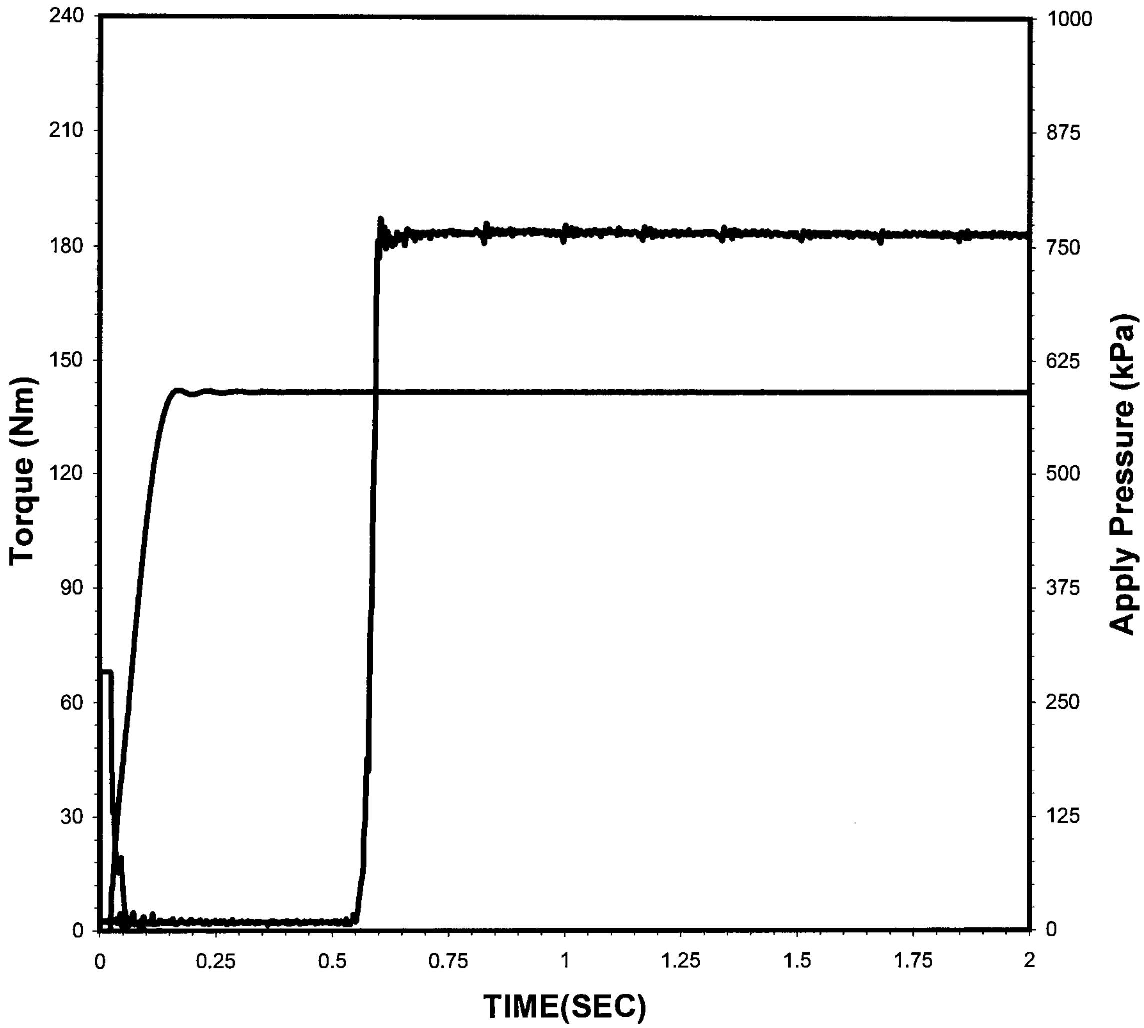
Apply Pressure:
At .25 Second: 835 kPa

Torque
Static Peak: 208 Nm
.25 Second: 199 Nm

Coefficient of Friction
Static Peak: 0.144
.25 Second: 0.138

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 10:48:54

Test Number: C4-6-1284

Fluid Code: LO250033

Cycle Number: 5500

PHASE B

Apply Pressure:
At .25 Second: 835 kPa

Torque
Static Peak: 225 Nm
.25 Second: 199 Nm

Coefficient of Friction
Static Peak: 0.155
.25 Second: 0.137

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted For

ARMY LAB

Oil Code:
LO250033

Test Number:
C2-5-1550

July 21, 2010

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

IX. Paper Clutch Friction Test

Test Laboratory: SWRI
Test Number: C2-5-1550
Friction Plate Batch: BATCH 5
Steel Plate Batch: 10/9/2008

Lab Fluid Code: LO-250033
Sponsor Fluid Code: LO250033
Completion Date: 07/21/10

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0010	0.0001
Clutch Plate	0.0810	0.0759

	Before	After
Pack Clearance	1.0922	1.5240

Reference Tests

Test Number	Test Date	Test Fluid
C2-0-1523	01/24/09	RDL-2746 08-05
C2-0-1534	11/26/09	RDL-2746 08-05
C2-0-1545	04/03/10	RDL-2746 08-05

	New	EOT
Viscosity at 40°C, cSt	54.02	44.06
Viscosity at 100°C, cSt	10.00	8.51
Iron Content, ppm	2	243

D5185	New Fluid (ppm)
Ba	<1
B	67
Ca	782
Mg	1102
P	1118
Si	7
Na	8
Zn	1294

Name: Matthew Jackson
Title: Manager

Signature:
Date: 7/30/10

ALLISON C- 4 PAPER FRICTION TEST
(Torque in N*m)

Sponsor Fluid Code: **LO250033** Test Number: **C2-5-1550**
Lab Fluid Code: **LO-250033** Fric. Plate Batch: **Batch 5**
Completion Date: **07/21/2010** Steel Plate Batch: **10/9/2008**

TORQUE

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.47	214	352	138	390	375
500	0.46	221	348	127	393	375
1000	0.44	229	341	112	378	366
2500	0.43	241	323	82	358	348
5000	0.43	246	321	75	355	341
7500	0.43	244	316	72	355	339
10000	0.43	244	315	71	344	335

COEFFICIENT OF FRICTION

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.47	0.104	0.171	0.067	0.190	0.183
500	0.46	0.108	0.169	0.061	0.191	0.183
1000	0.44	0.112	0.166	0.054	0.184	0.178
2500	0.43	0.117	0.157	0.040	0.174	0.169
5000	0.43	0.120	0.156	0.036	0.173	0.166
7500	0.43	0.119	0.154	0.035	0.173	0.165
10000	0.43	0.119	0.153	0.034	0.168	0.163

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.470	0.430	-8.51	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.104	0.119	14.42	P
Static Friction Coeff.	N/A	N/A	0.171	0.153	-10.53	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.190	0.168	-11.58	
0.25 Second Low Speed Coeff.	N/A	N/A	0.183	0.163	-10.93	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-PAPER FRICTION TEST

(all units in mm)

Candidate Fluid: LO250033 **Test Number : C2-5-1550** **Completion Date : 7/21/2010**

Lab Fluid Code : LO-250033 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 5**

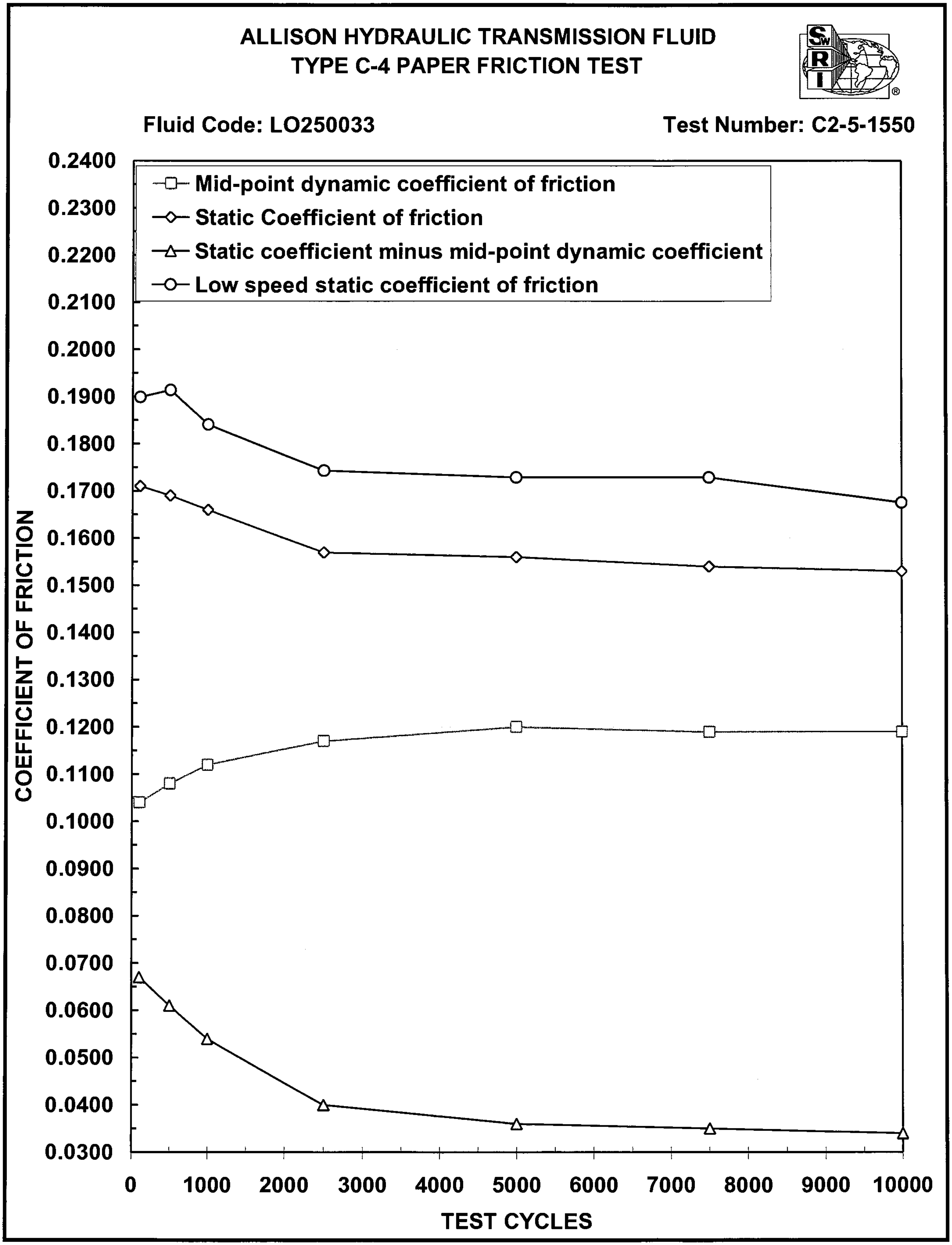
Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.0350	1.9570	2.0300	1.9570	0.0780		0.0730
	120	2.0320	1.9510	2.0250	1.9490	0.0810		0.0760
	240	2.0360	1.9560	2.0340	1.9560	0.0800		0.0780
	Average					0.0797	0.0777	0.0757
5	Top	2.0330	1.9600	2.0330	1.9590	0.0730		0.0740
	120	2.0380	1.9630	2.0340	1.9620	0.0750		0.0720
	240	2.0330	1.9570	2.0280	1.9540	0.0760		0.0740
	Average					0.0747	0.0740	0.0733
STEELS SEPARATORS								
1	Top	1.7620	1.7620	1.7620	1.7620	0.0000		0.0000
	120	1.7630	1.7630	1.7640	1.7640	0.0000		0.0000
	240	1.7630	1.7630	1.7630	1.7630	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7630	1.7630	1.7660	1.7660	0.0000		0.0000
	120	1.7600	1.7600	1.7610	1.7610	0.0000		0.0000
	240	1.7610	1.7610	1.7610	1.7610	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
4	Top	1.7620	1.7620	1.7630	1.7630	0.0000		0.0000
	120	1.7620	1.7620	1.7620	1.7620	0.0000		0.0000
	240	1.7620	1.7610	1.7620	1.7610	0.0010		0.0010
	Average					0.0003	0.0003	0.0003
6	Top	1.7560	1.7560	1.7560	1.7560	0.0000		0.0000
	120	1.7560	1.7560	1.7560	1.7560	0.0000		0.0000
	240	1.7560	1.7560	1.7560	1.7560	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T.: PLATES IN GOOD CONDITION
(Anything Unusual)

Test Date and Operator's Name: 7/21/2010 JOE M

Reviewed By (Signature and Date)
7/30/10

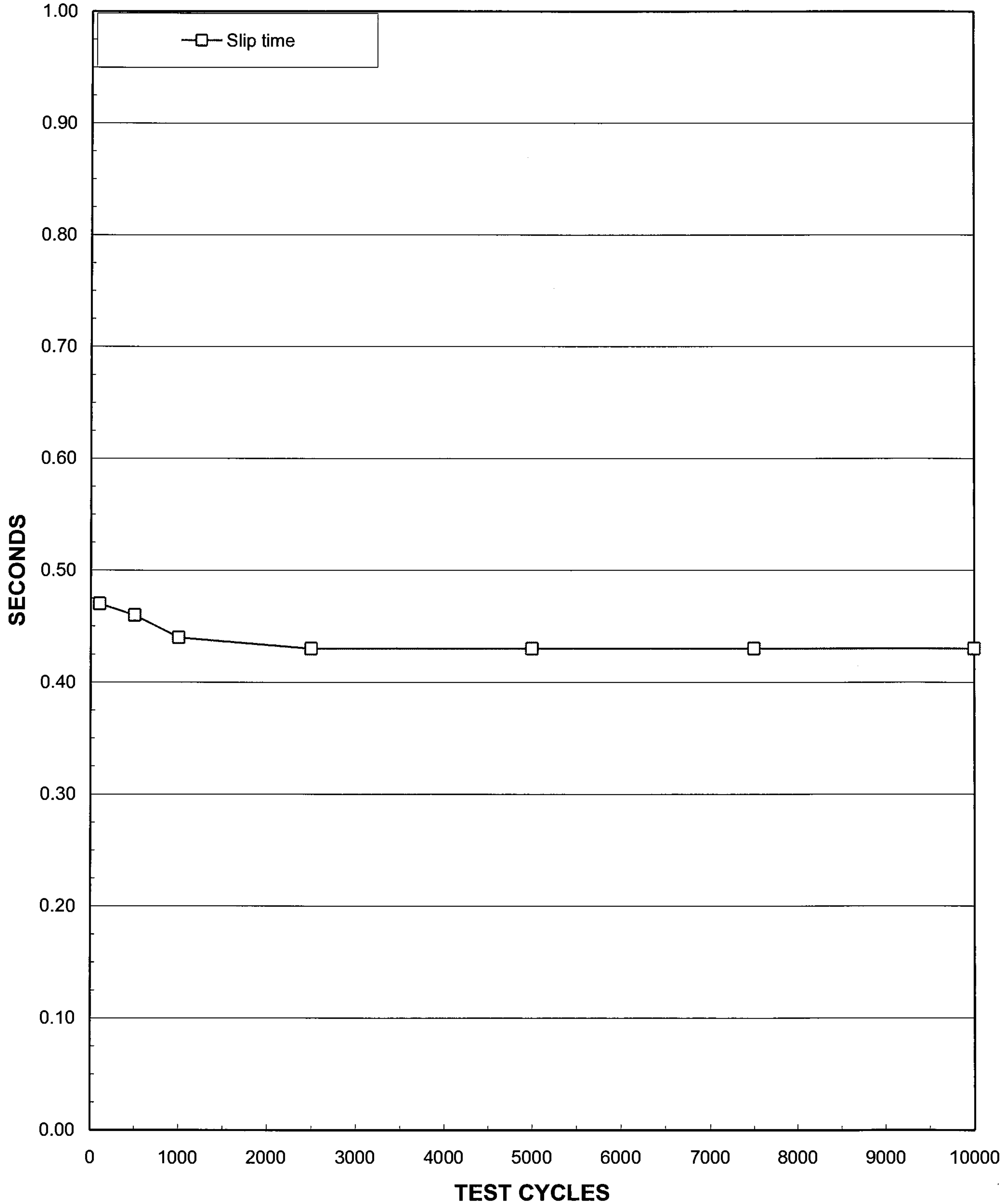
Pack ID#: 4409

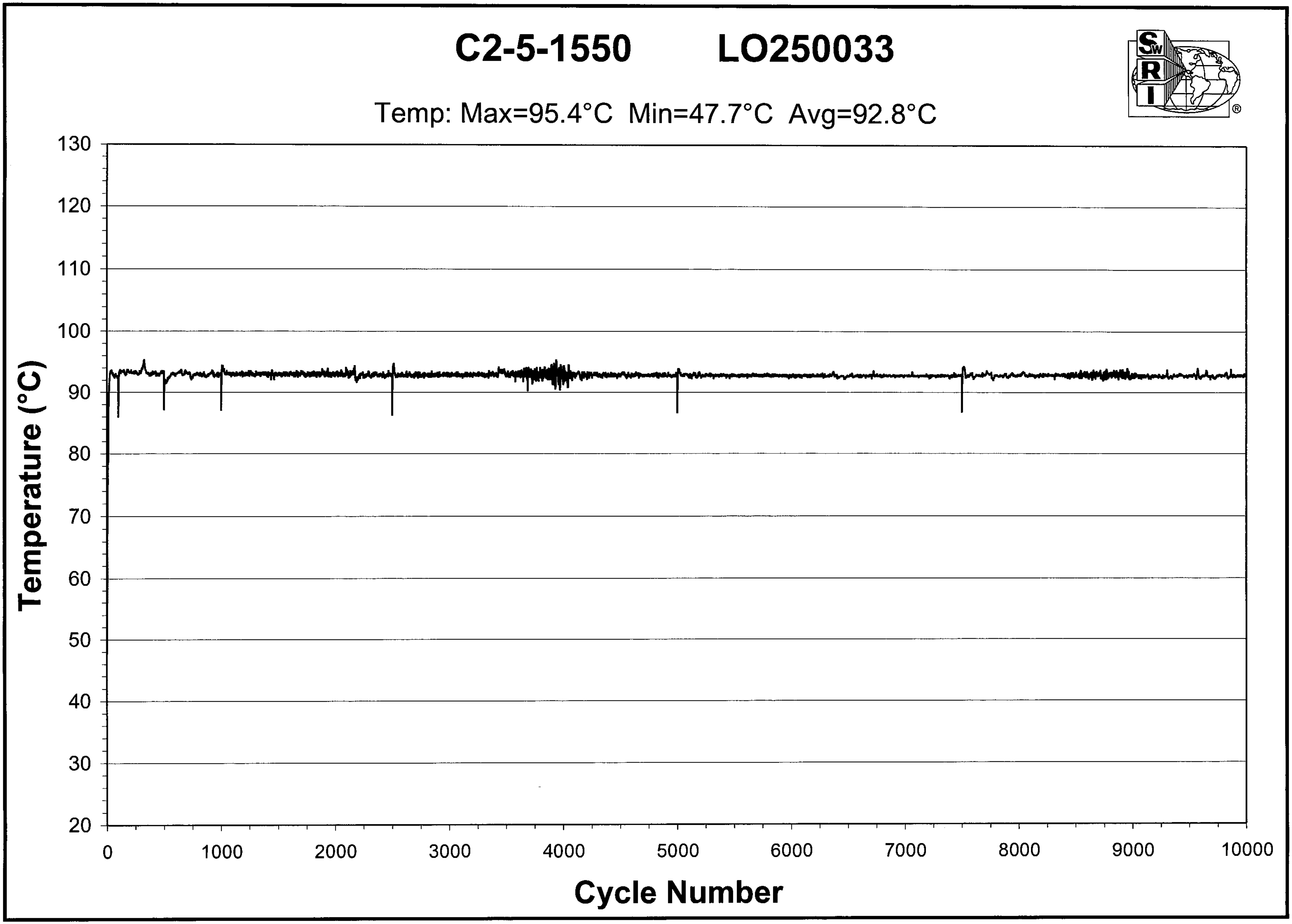

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO250033
Test Number: C2-5-1550
Mid-point dynamic coefficient of friction
Static Coefficient of friction
Static coefficient minus mid-point dynamic coefficient
Low speed static coefficient of friction
COEFFICIENT OF FRICTION
TEST CYCLES
0.2400
0.2300
0.2200
0.2100
0.2000
0.1900
0.1800
0.1700
0.1600
0.1500
0.1400
0.1300
0.1200
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0.0300
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST

Fluid Code: LO250033

Test Number: C2-5-1550

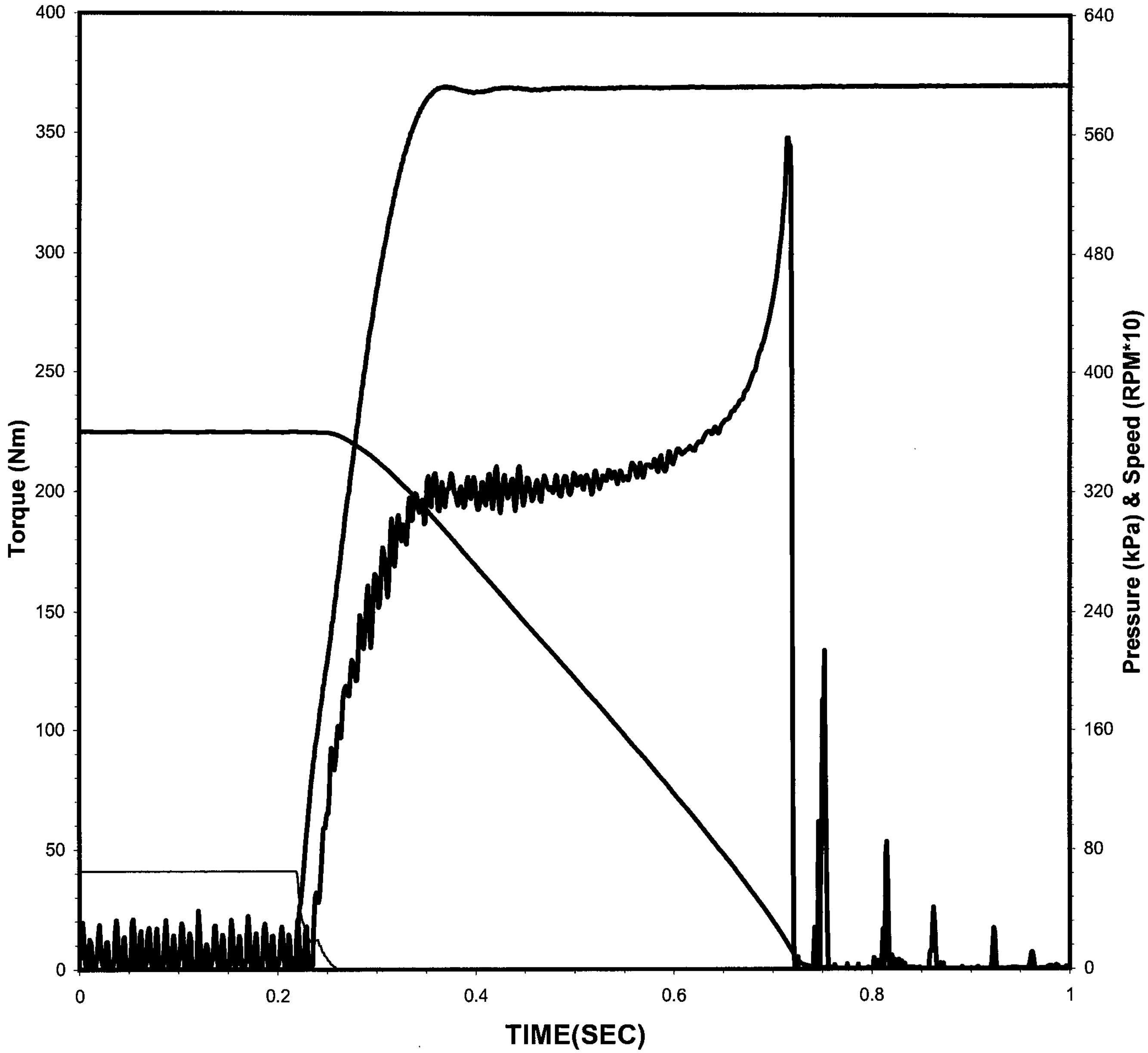



C2-5-1550 LO250033
Temp: Max=95.4°C Min=47.7°C Avg=92.8°C
Temperature (°C)
130
120
110
100
90
80
70
60
50
40
30
20
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cycle Number

DYNAMIC TRACES

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/19/2010**
Time of Test:	**13:20:50**
Test Number:	**C2-5-1550**
Fluid Code:	**LO250033**
Cycle Number:	**10**
Temperature:	**83.4 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**589 kPa** (586 ± 7 KPa)
Apply Rate:	**0.14 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.6 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.502 Sec**

Torque

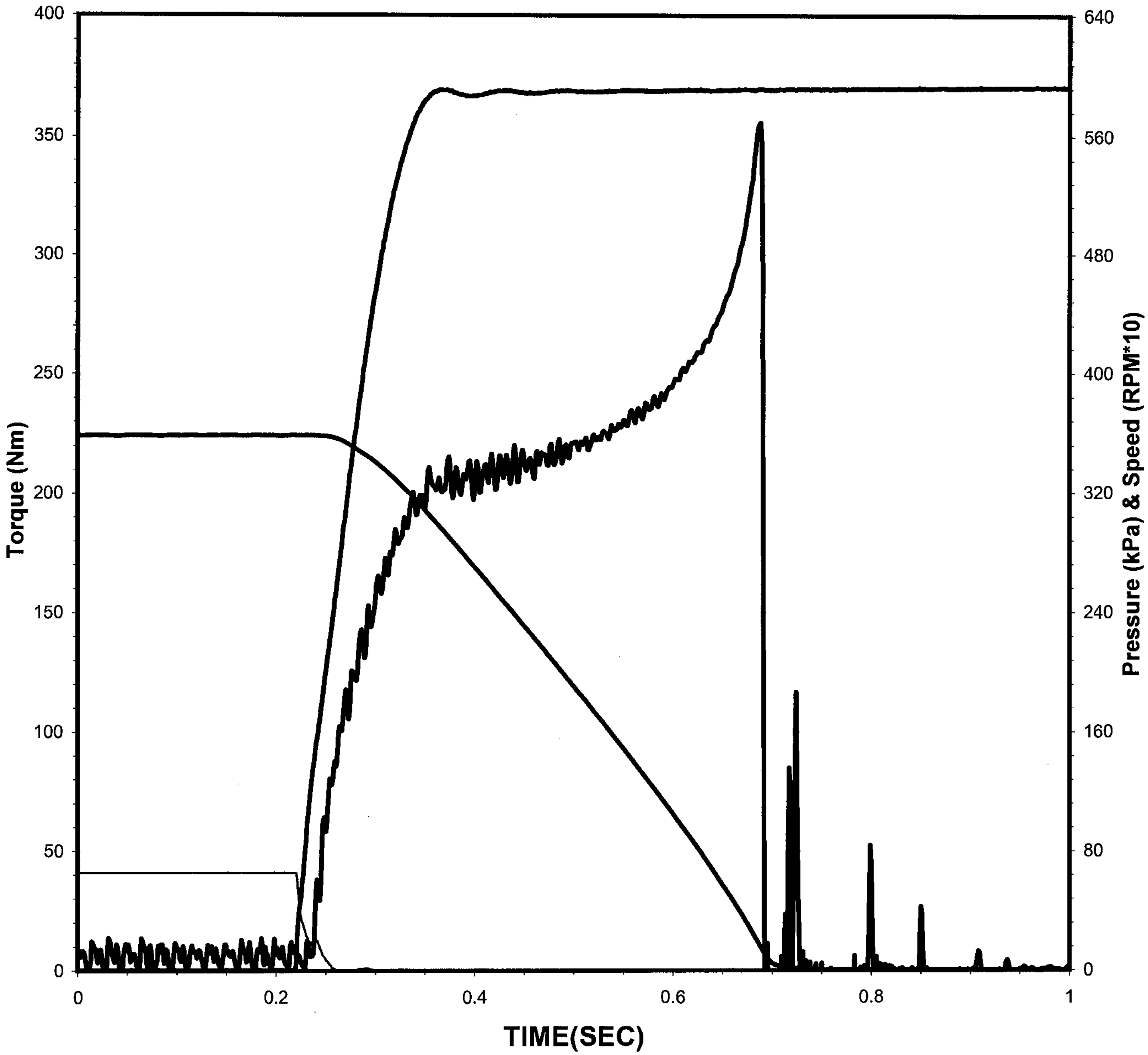
0.2 Sec Dyn:	**200 N*m**
Midpoint Dyn:	**200 N*m**
LwSpd Dynamic:	**345 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.097**
Midpoint Dyn:	**0.098**
LwSpd Dynamic:	**0.168**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/19/2010**
Time of Test:	**13:43:22**
Test Number:	**C2-5-1550**
Fluid Code:	**LO250033**
Cycle Number:	**99**
Temperature:	**92.5 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**589 kPa** (586 ± 7 KPa)
Apply Rate:	**0.14 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.5 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.471 Sec**

Torque

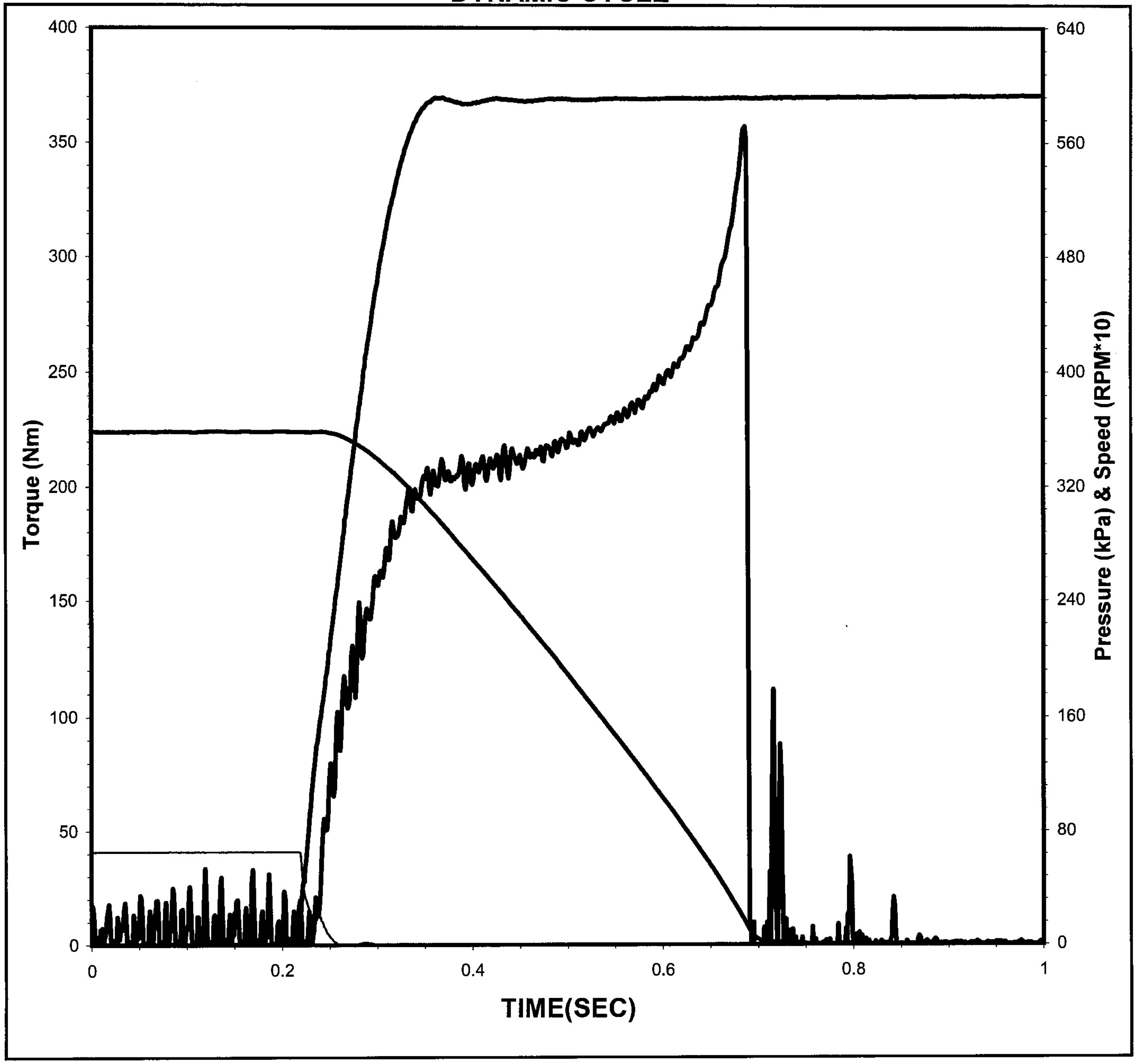
0.2 Sec Dyn:	**209 N*m**
Midpoint Dyn:	**212 N*m**
LwSpd Dynamic:	**355 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.102**
Midpoint Dyn:	**0.103**
LwSpd Dynamic:	**0.173**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/19/2010

Time of Test: 13:43:37

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 100

Temperature: 92.2 °C
(93.3 ± 3.0 °C)

Apply Pressure: 589 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.473 Sec

Torque

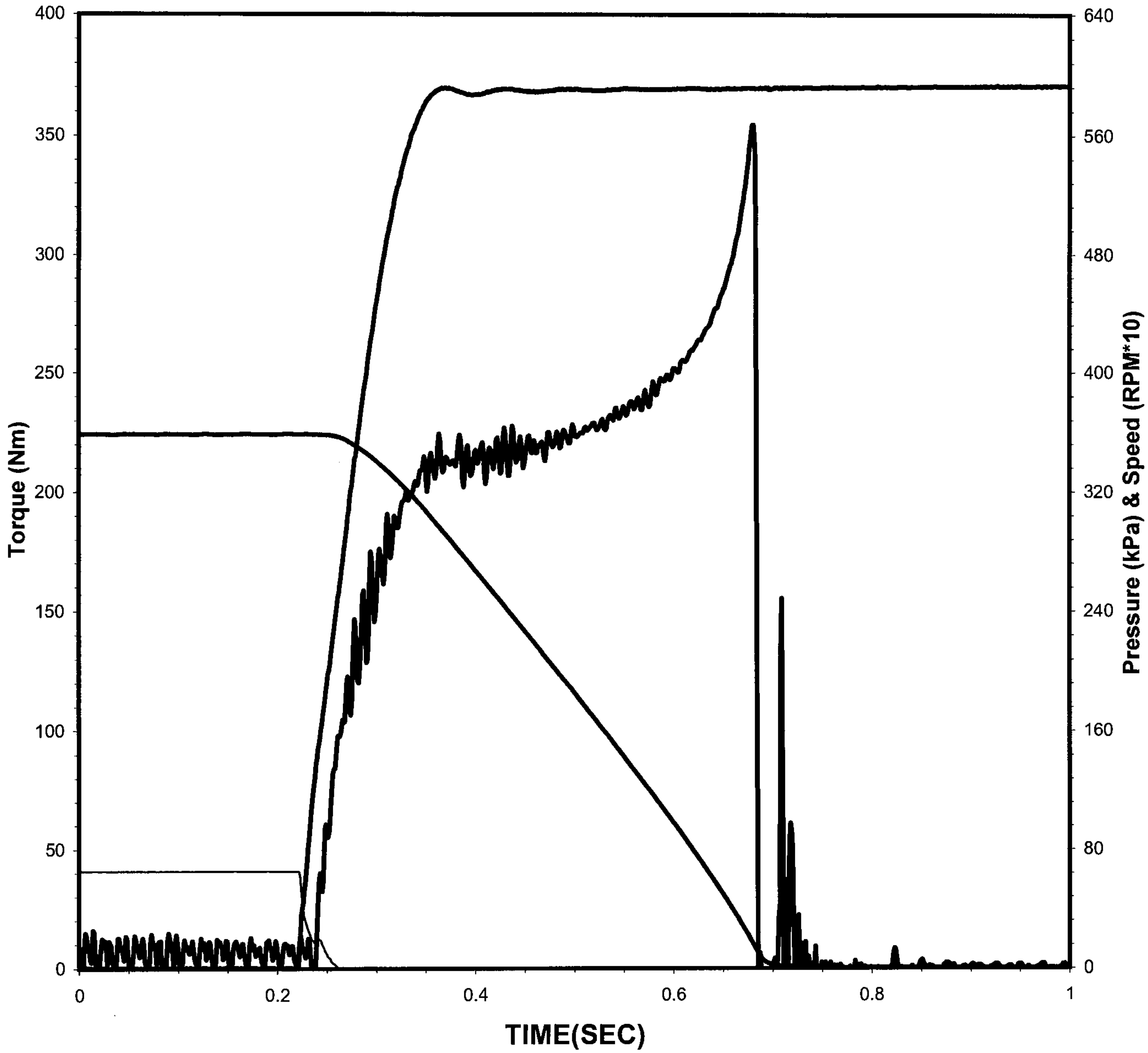
0.2 Sec Dyn:	**209 N*m**
Midpoint Dyn:	**212 N*m**
LwSpd Dynamic:	**352 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.102**
Midpoint Dyn:	**0.103**
LwSpd Dynamic:	**0.171**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/19/2010
Time of Test:	13:44:08
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	101
Temperature:	85.9 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	590 kPa
	(586 ± 7 KPa)
Apply Rate:	0.14 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.6 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.462 Sec

Torque

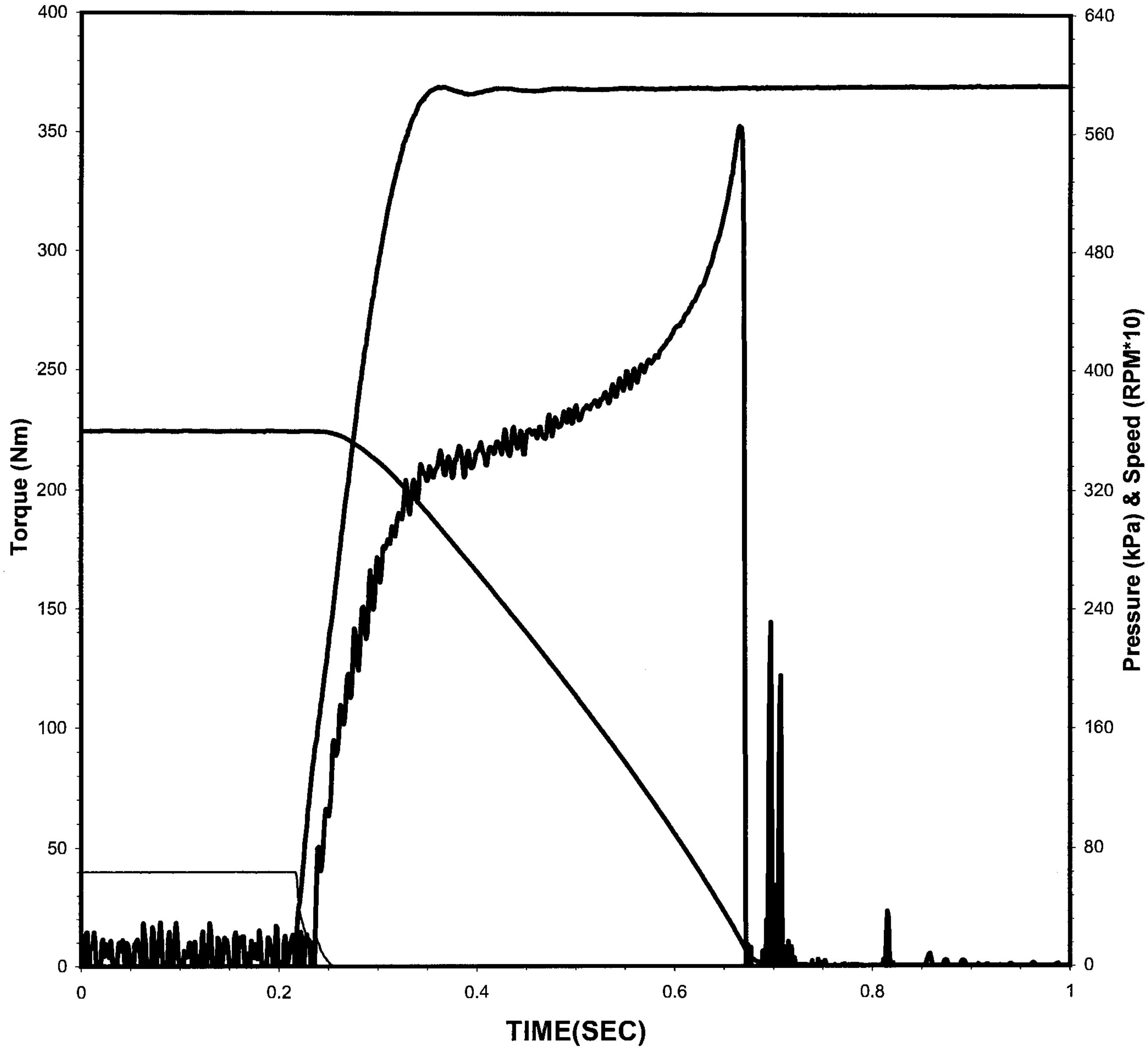
0.2 Sec Dyn:	216 N*m
Midpoint Dyn:	218 N*m
LwSpd Dynamic:	350 N*m

Coefficient of Friction

.2 Sec Dyn:	0.105
Midpoint Dyn:	0.106
LwSpd Dynamic:	0.170

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/19/2010
Time of Test:	15:23:38
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	499
Temperature:	93.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.454 Sec

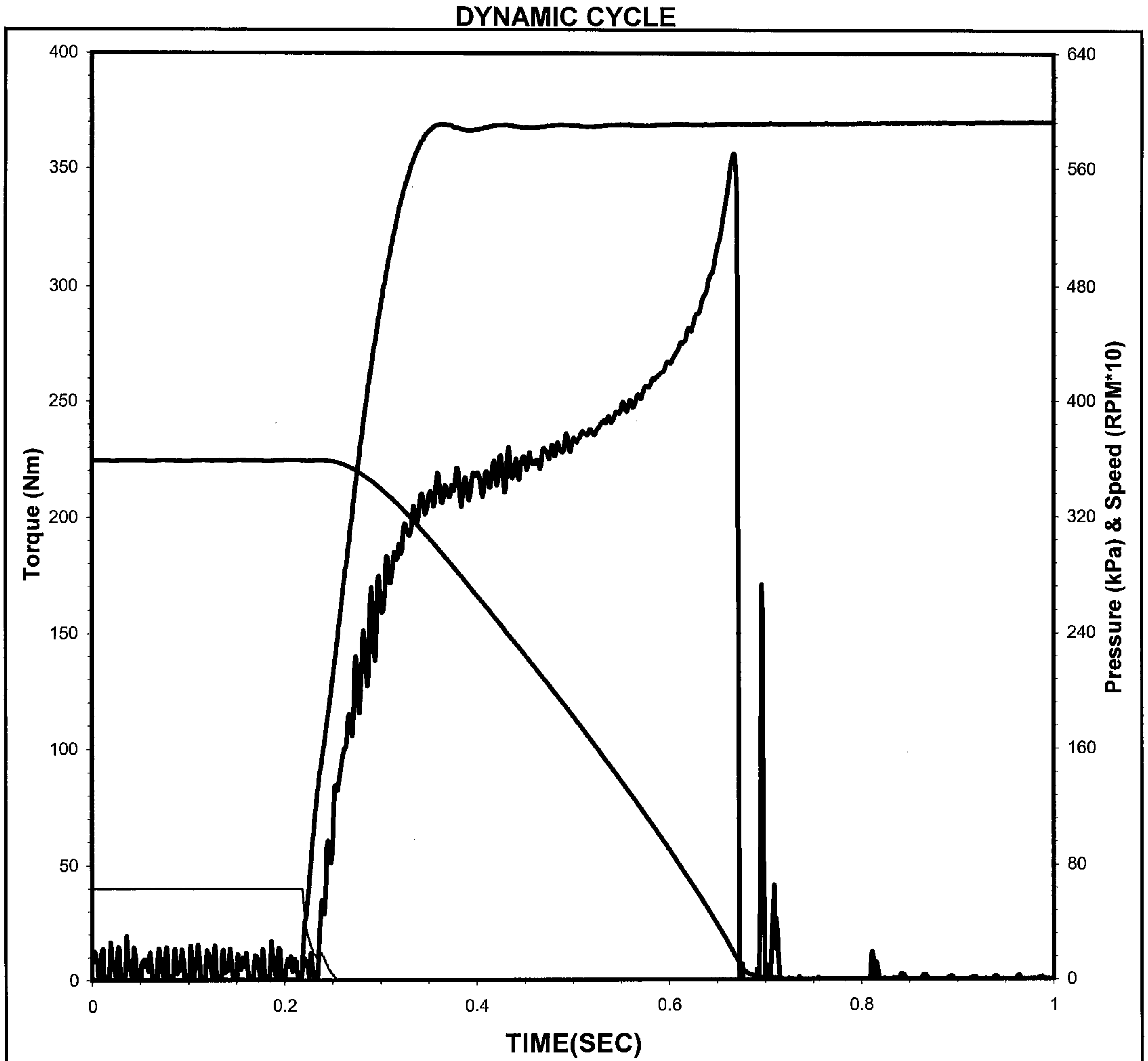
Torque

0.2 Sec Dyn:	217 N*m
Midpoint Dyn:	221 N*m
LwSpd Dynamic:	348 N*m

Coefficient of Friction

.2 Sec Dyn:	0.106
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.169

ALLISON C-4 PAPER DATA



Date of Test:	7/19/2010
Time of Test:	15:23:53
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	500
Temperature:	93.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.454 Sec

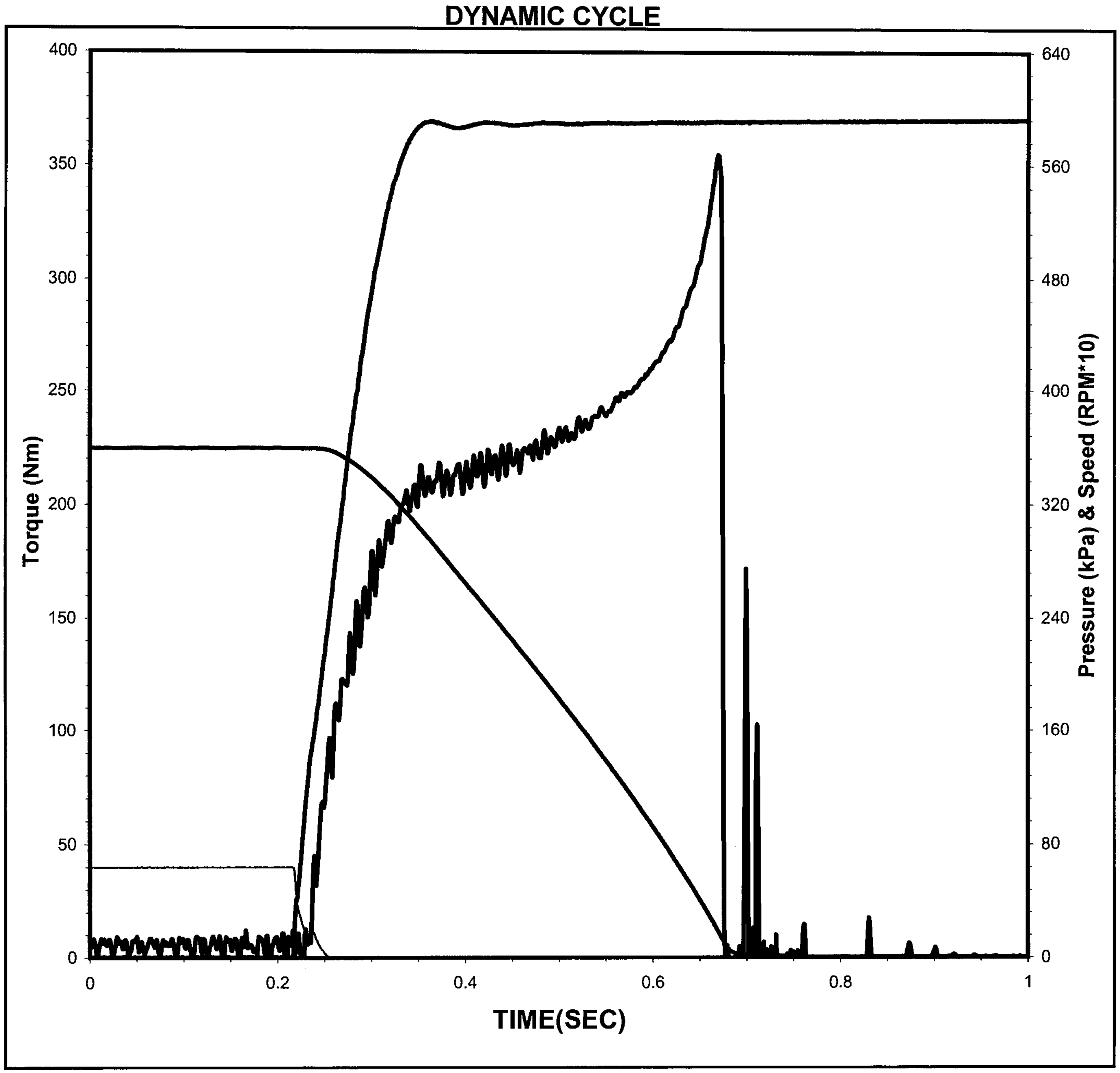
Torque

0.2 Sec Dyn:	219 N*m
Midpoint Dyn:	222 N*m
LwSpd Dynamic:	351 N*m

Coefficient of Friction

.2 Sec Dyn:	0.107
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.171

ALLISON C-4 PAPER DATA



Date of Test:	7/19/2010
Time of Test:	15:24:24
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	501
Temperature:	87.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.459 Sec

Torque

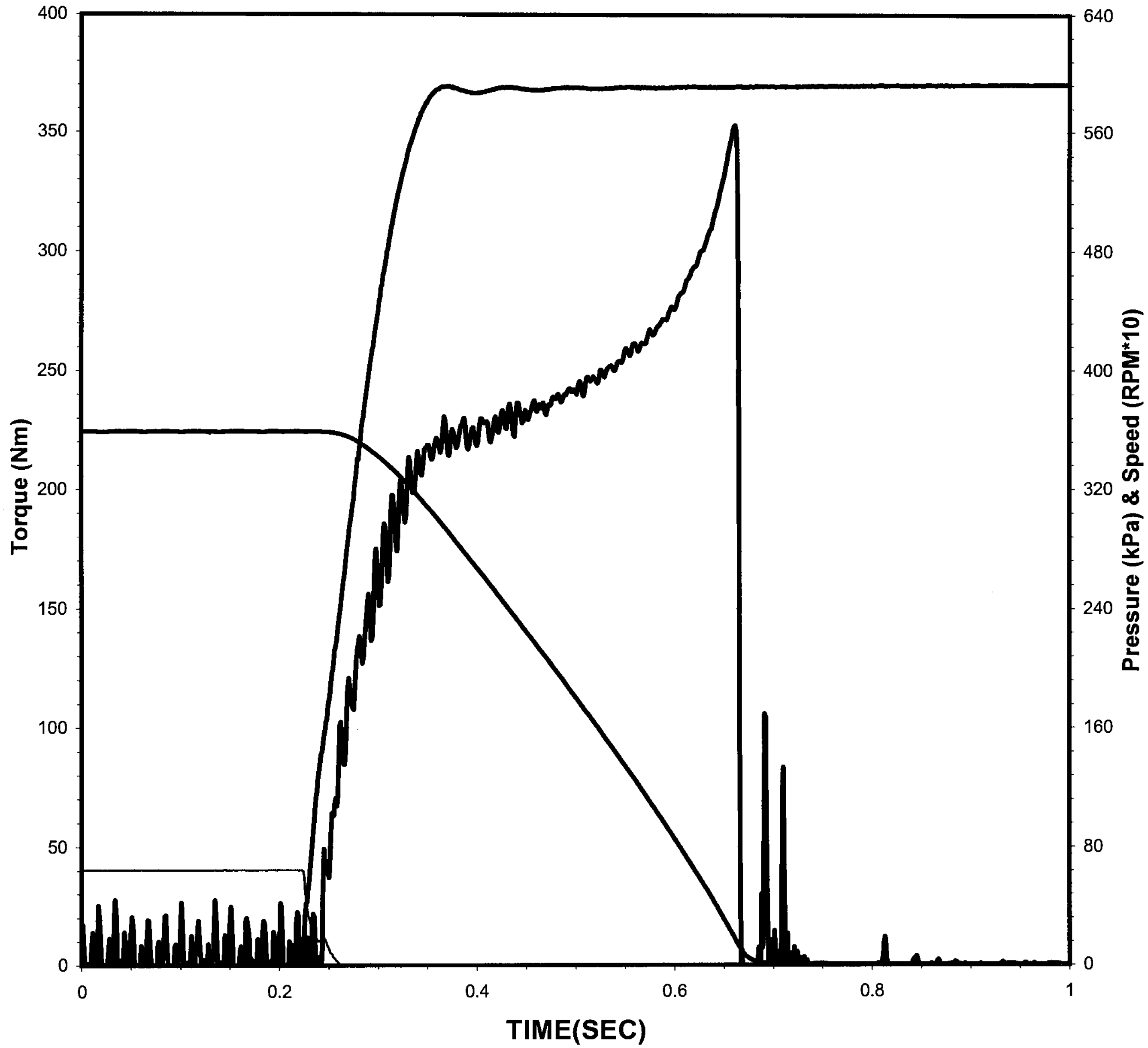
0.2 Sec Dyn:	216 N*m
Midpoint Dyn:	220 N*m
LwSpd Dynamic:	346 N*m

Coefficient of Friction

.2 Sec Dyn:	0.105
Midpoint Dyn:	0.107
LwSpd Dynamic:	0.168

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/19/2010**
Time of Test:	**17:28:54**
Test Number:	**C2-5-1550**
Fluid Code:	**LO250033**
Cycle Number:	**999**
Temperature:	**92.9 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**589 kPa** (586 ± 7 KPa)
Apply Rate:	**0.14 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.8 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.442 Sec**

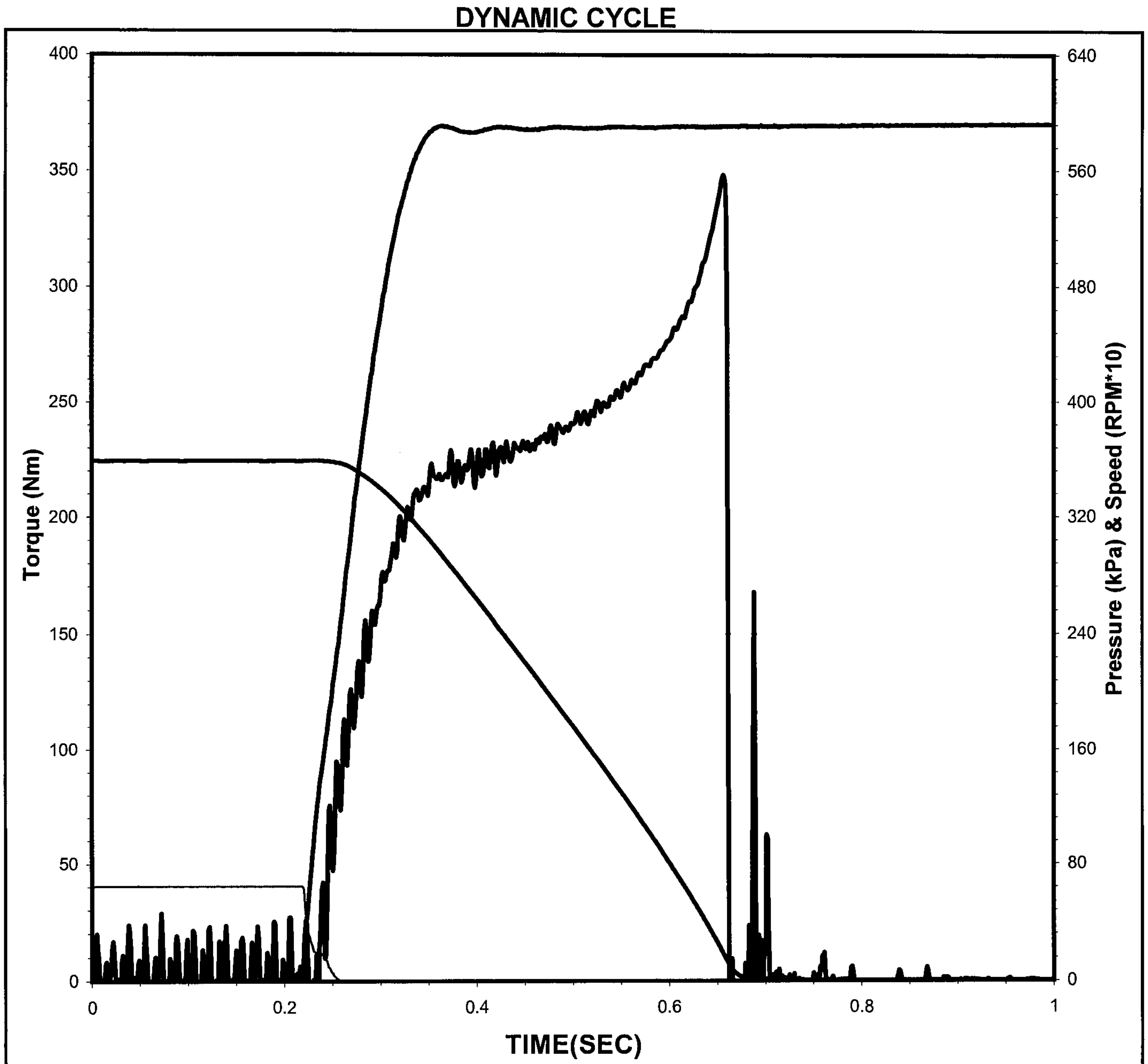
Torque

0.2 Sec Dyn:	**230 N*m**
Midpoint Dyn:	**232 N*m**
LwSpd Dynamic:	**344 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.112**
Midpoint Dyn:	**0.113**
LwSpd Dynamic:	**0.167**

ALLISON C-4 PAPER DATA



Date of Test:	7/19/2010
Time of Test:	17:29:09
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	1000
Temperature:	93.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.442 Sec

Torque

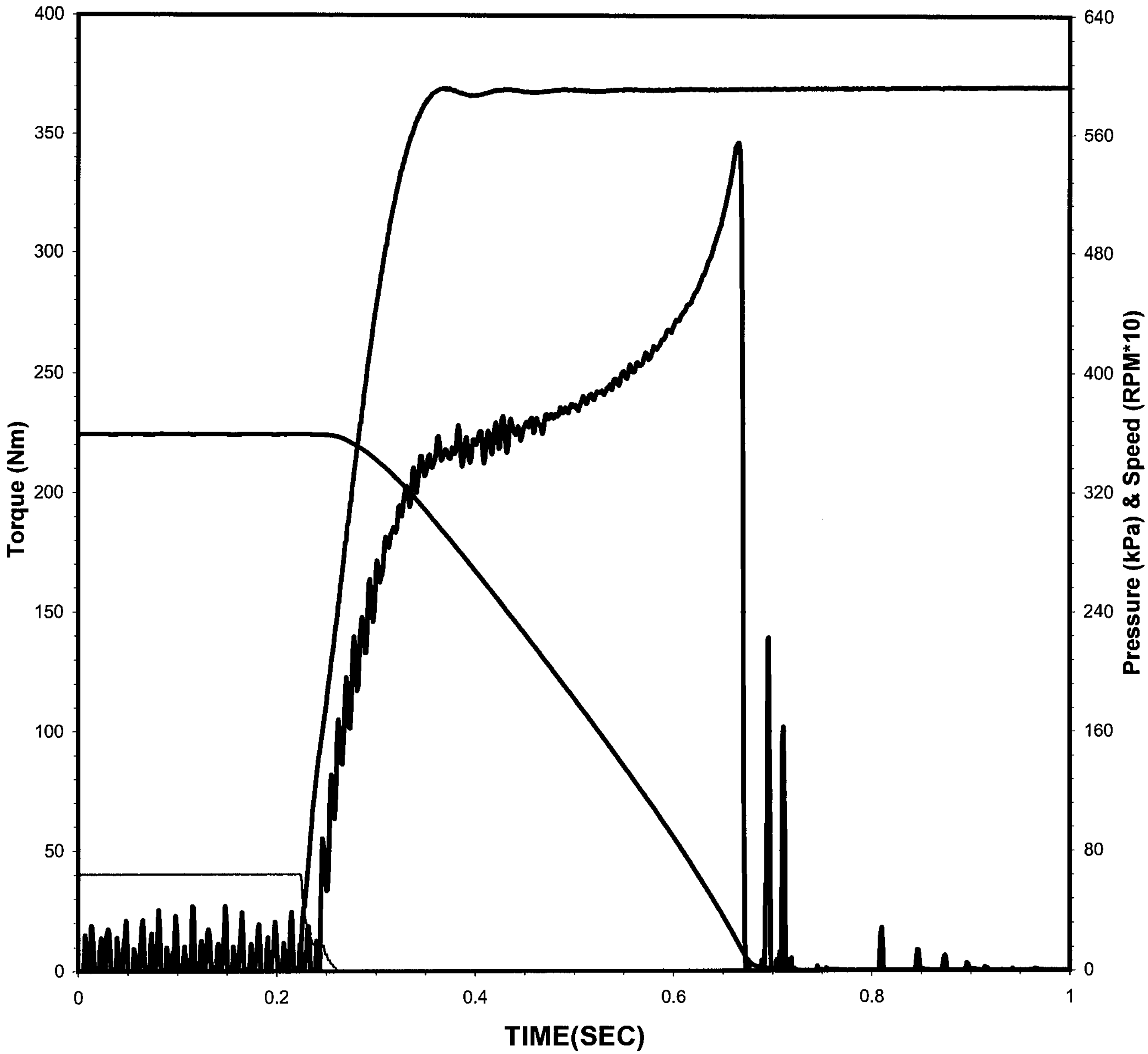
0.2 Sec Dyn:	226 N*m
Midpoint Dyn:	229 N*m
LwSpd Dynamic:	344 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.112
LwSpd Dynamic:	0.167

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/19/2010

Time of Test: 17:29:40

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 1001

Temperature: 87.0 °C
(93.3 ± 3.0 °C)

Apply Pressure: 589 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.448 Sec

Torque

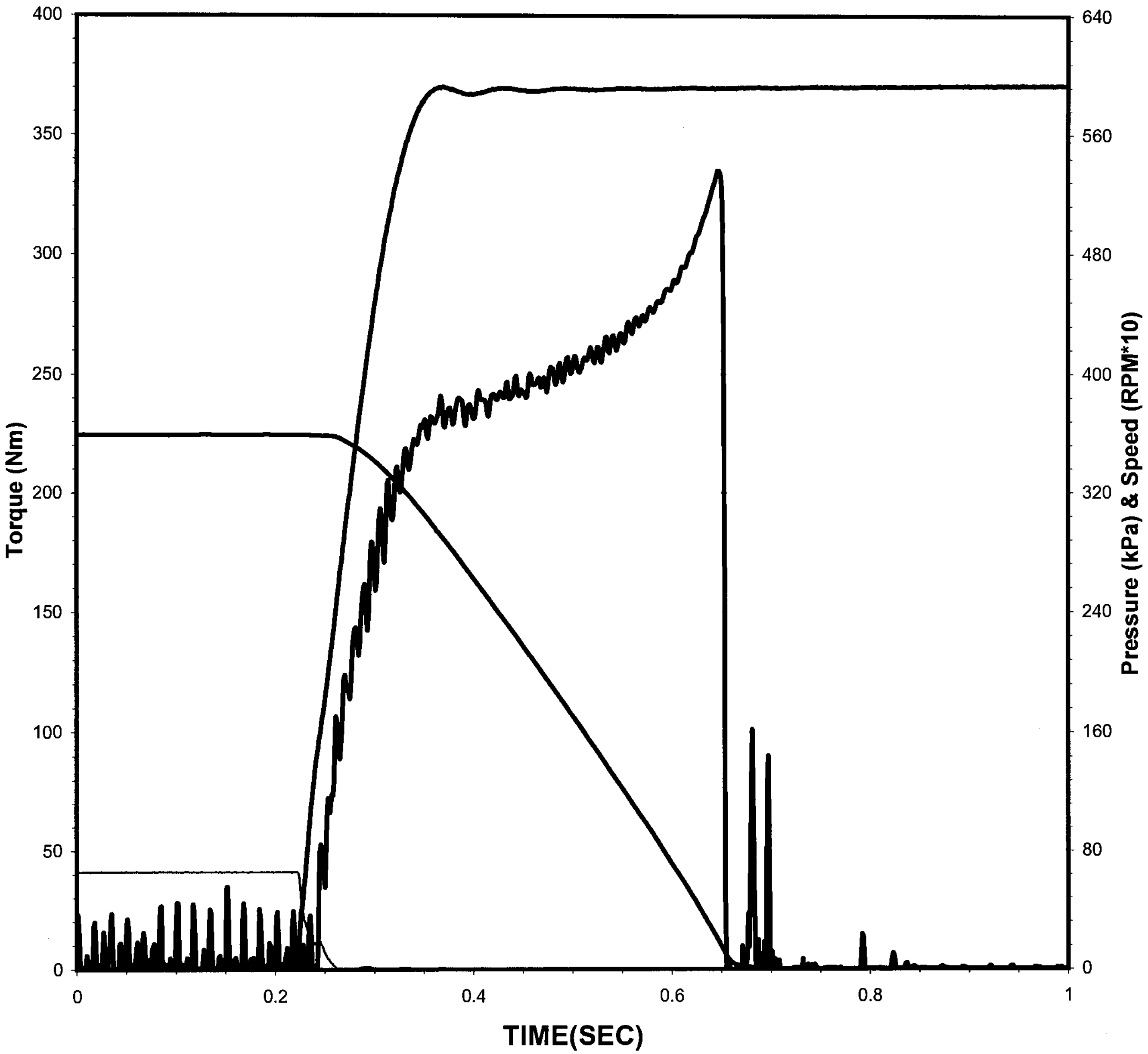
0.2 Sec Dyn:	224 N*m
Midpoint Dyn:	227 N*m
LwSpd Dynamic:	336 N*m

Coefficient of Friction

.2 Sec Dyn:	0.109
Midpoint Dyn:	0.110
LwSpd Dynamic:	0.164

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/19/2010
Time of Test:	23:44:10
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	2499
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.431 Sec

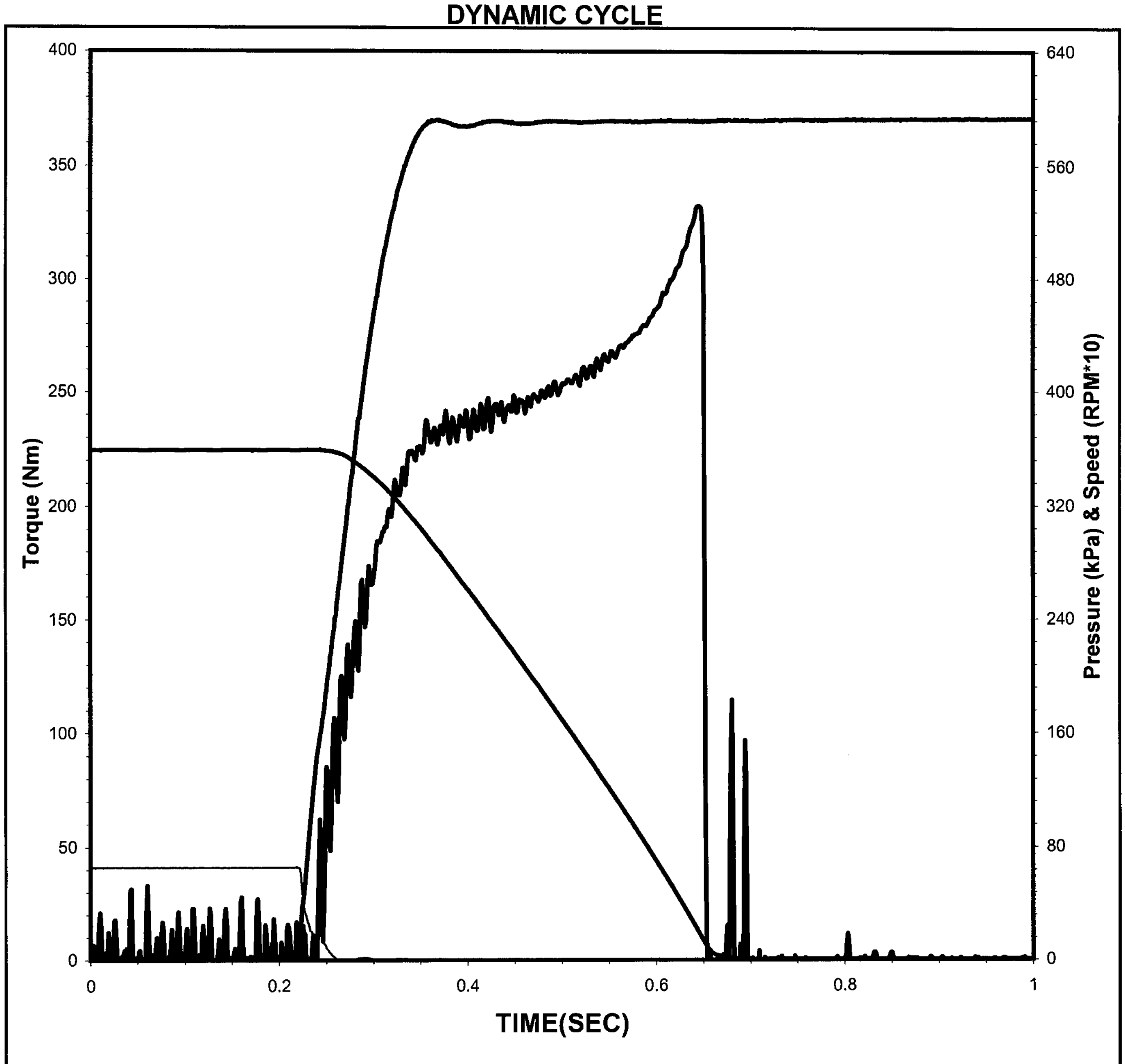
Torque

0.2 Sec Dyn:	241 N*m
Midpoint Dyn:	242 N*m
LwSpd Dynamic:	328 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.118
LwSpd Dynamic:	0.160

ALLISON C-4 PAPER DATA



Date of Test:	7/19/2010
Time of Test:	23:44:26
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	2500
Temperature:	92.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.432 Sec

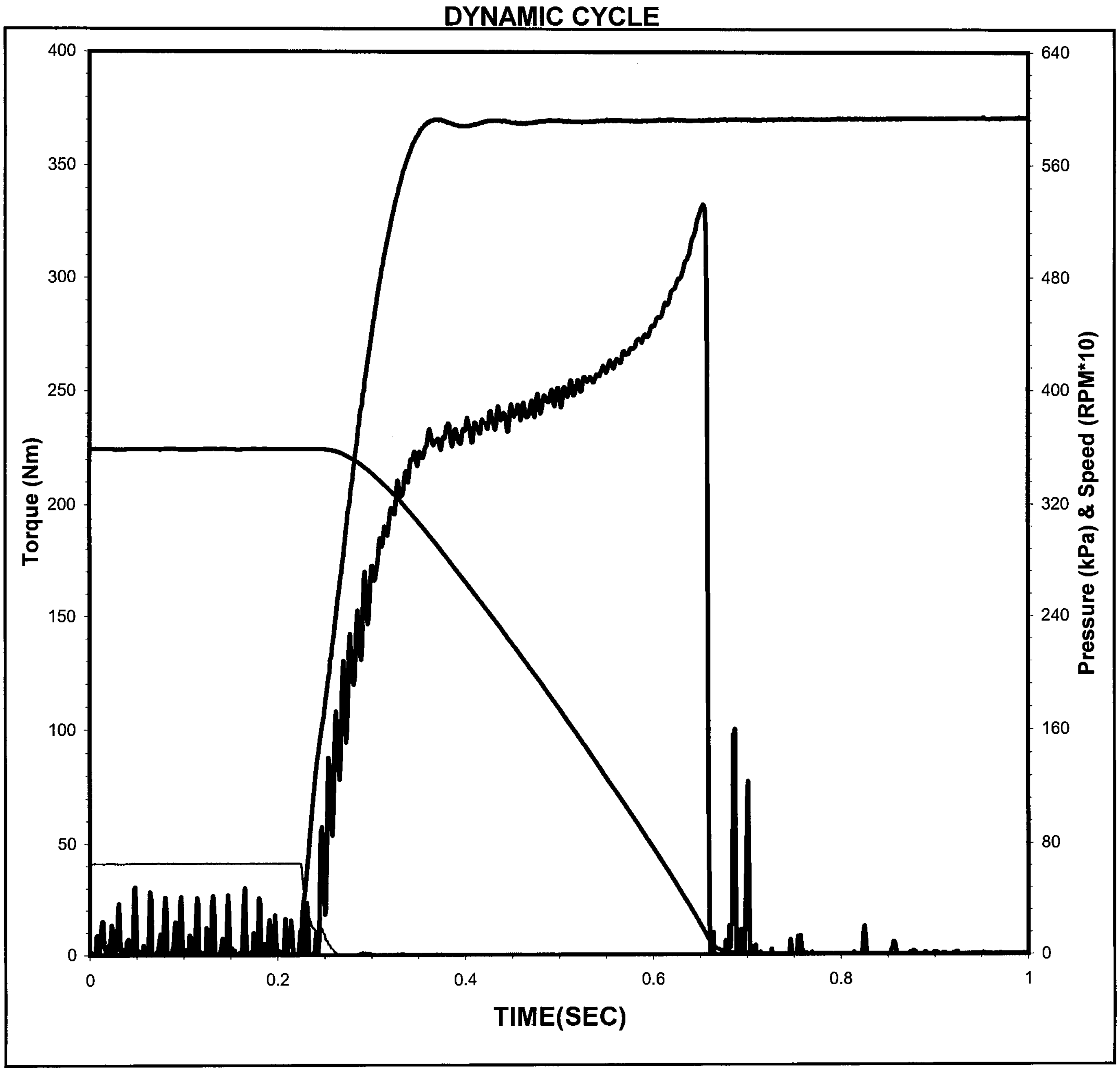
Torque

0.2 Sec Dyn:	240 N*m
Midpoint Dyn:	242 N*m
LwSpd Dynamic:	320 N*m

Coefficient of Friction

.2 Sec Dyn:	0.117
Midpoint Dyn:	0.118
LwSpd Dynamic:	0.156

ALLISON C-4 PAPER DATA



Date of Test:	7/19/2010
Time of Test:	23:44:57
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	2501
Temperature:	86.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.436 Sec

Torque

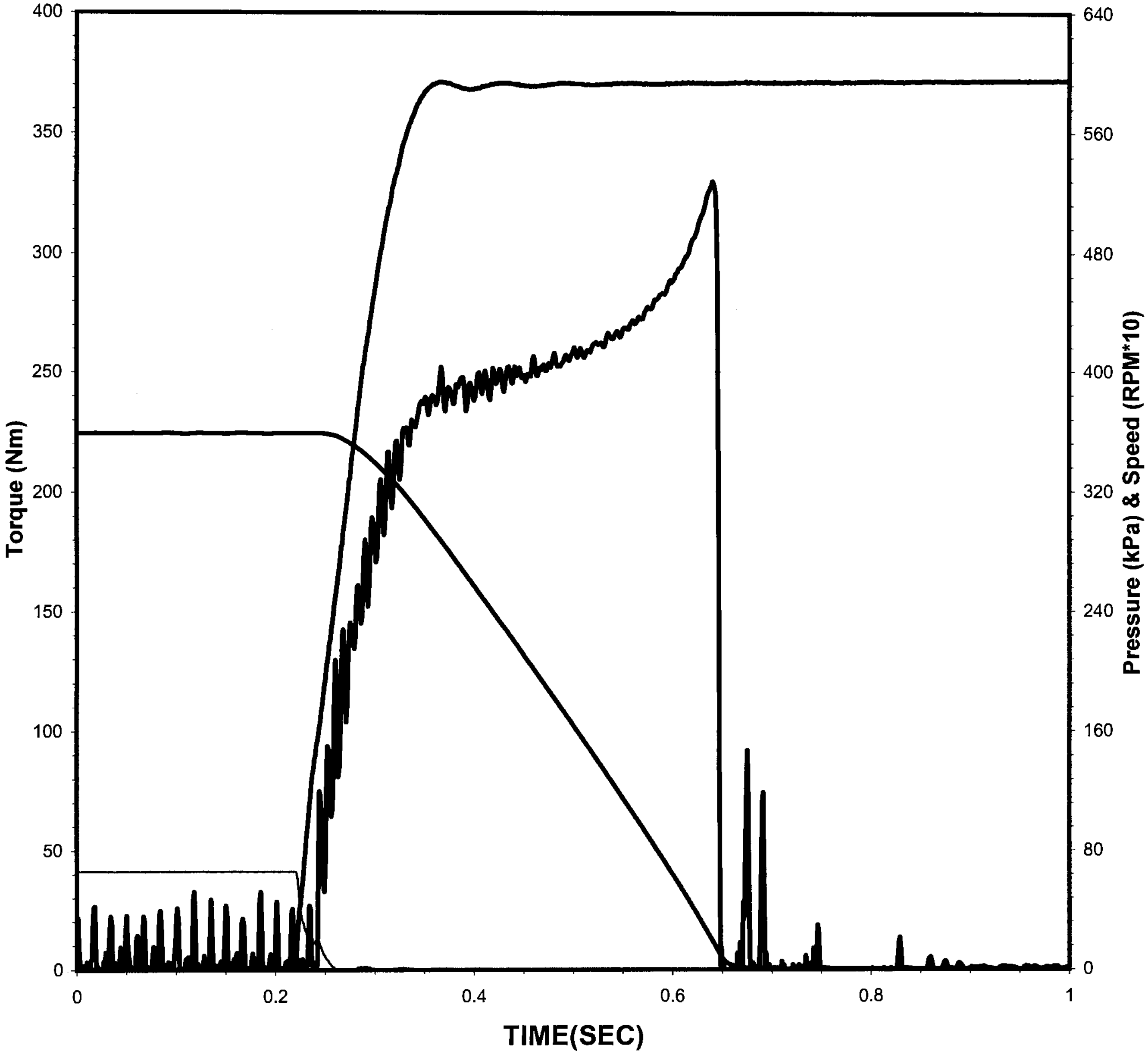
0.2 Sec Dyn:	236 N*m
Midpoint Dyn:	238 N*m
LwSpd Dynamic:	321 N*m

Coefficient of Friction

.2 Sec Dyn:	0.115
Midpoint Dyn:	0.116
LwSpd Dynamic:	0.156

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/20/2010
Time of Test:	10:09:27
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	4999
Temperature:	92.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	592 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.427 Sec

Torque

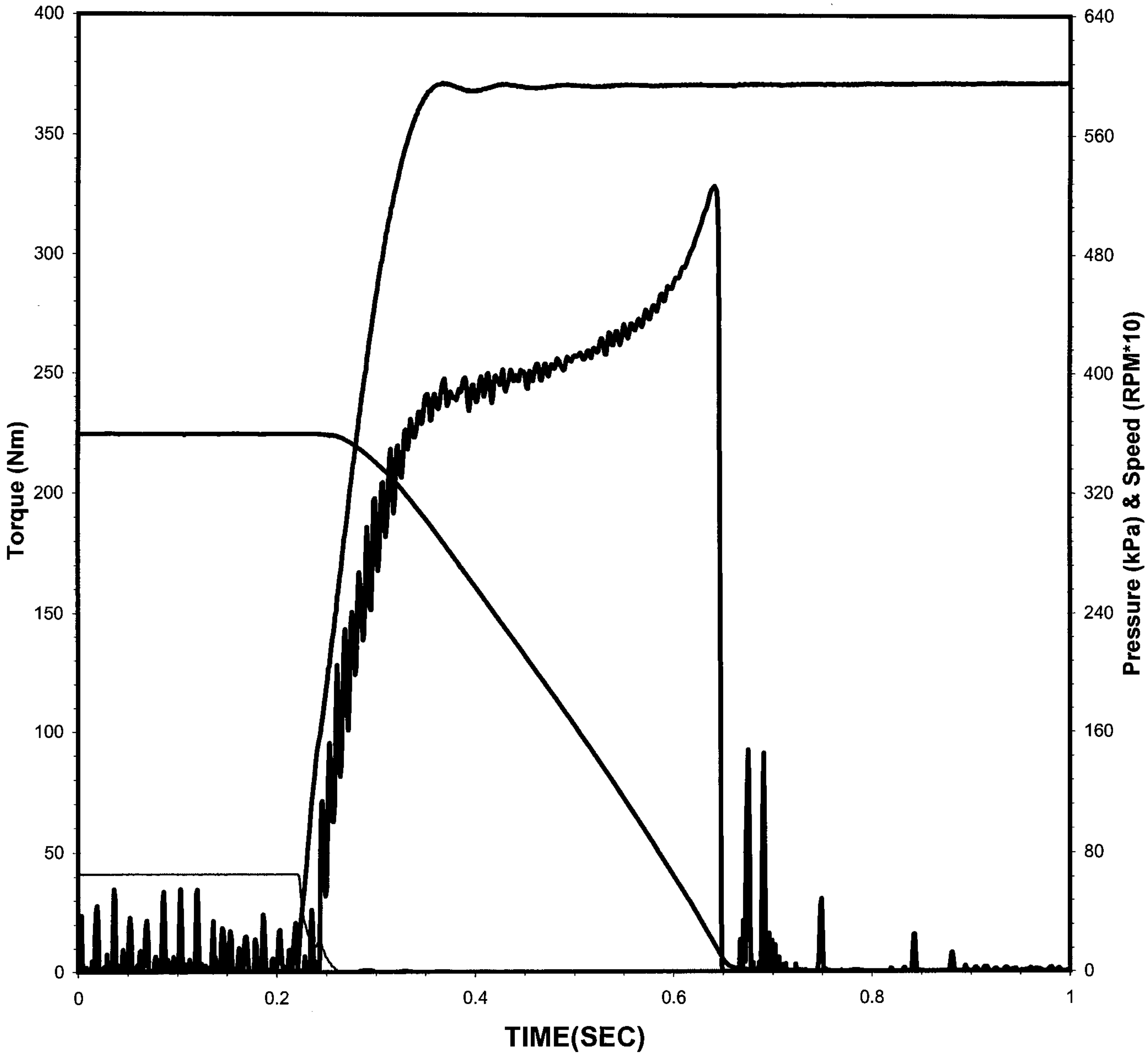
0.2 Sec Dyn:	245 N*m
Midpoint Dyn:	247 N*m
LwSpd Dynamic:	316 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.154

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/20/2010
Time of Test:	10:09:42
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	5000
Temperature:	92.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	592 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.426 Sec

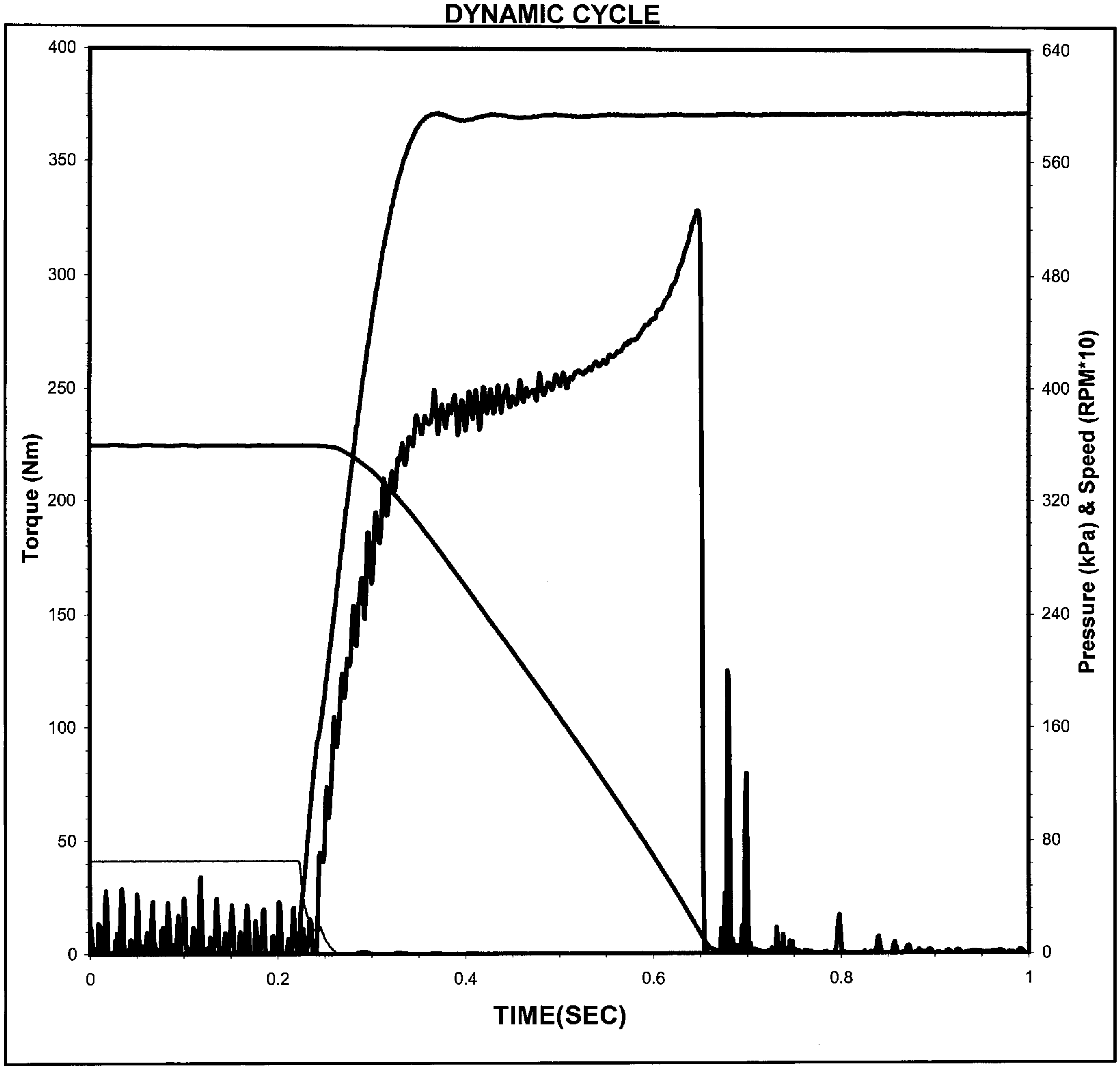
Torque

0.2 Sec Dyn:	245 N*m
Midpoint Dyn:	247 N*m
LwSpd Dynamic:	322 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.157

ALLISON C-4 PAPER DATA



Date of Test:	7/20/2010
Time of Test:	10:10:13
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	5001
Temperature:	86.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	592 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.43 Sec

Torque

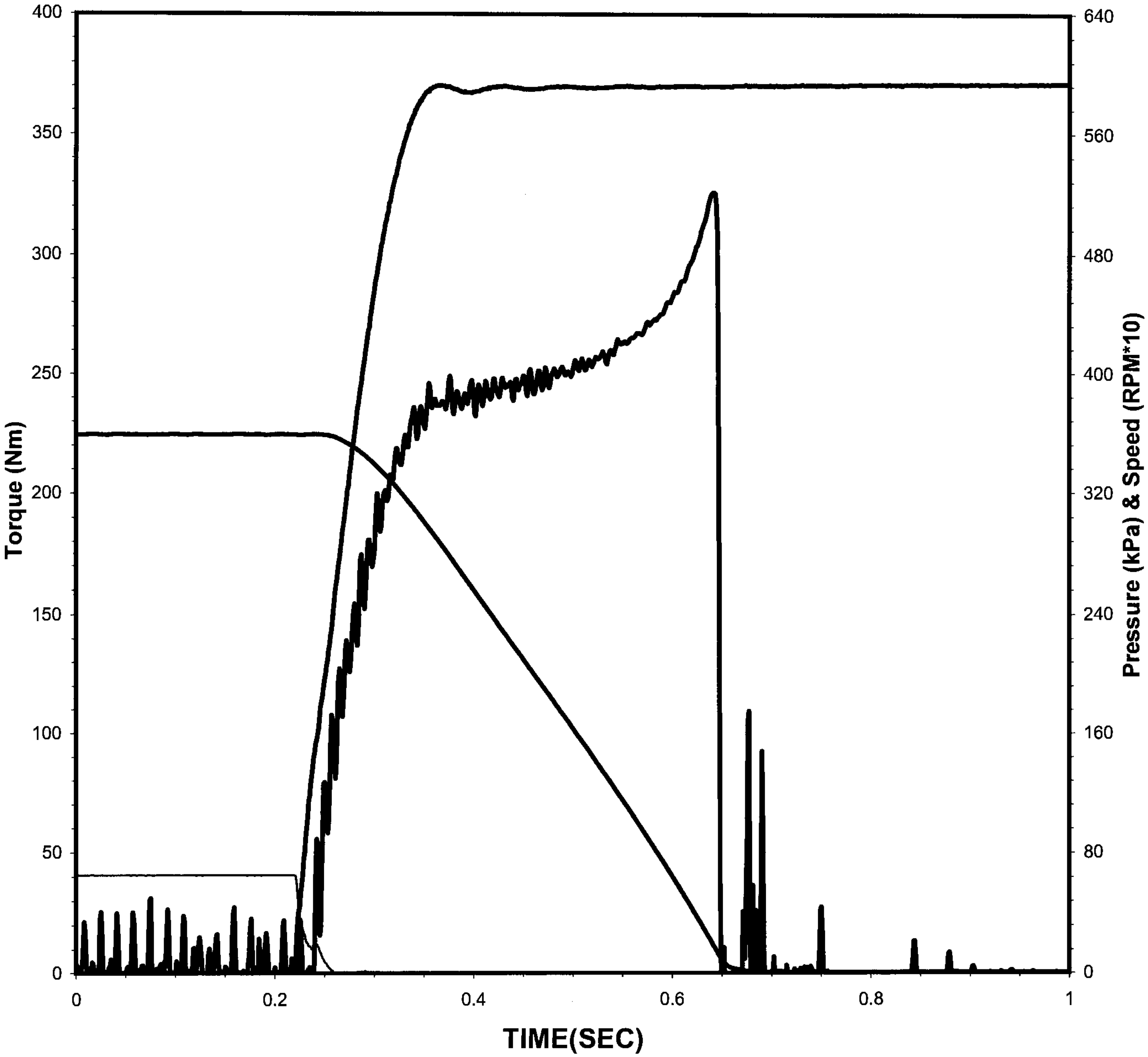
0.2 Sec Dyn:	243 N*m
Midpoint Dyn:	244 N*m
LwSpd Dynamic:	325 N*m

Coefficient of Friction

.2 Sec Dyn:	0.118
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.158

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/20/2010

Time of Test: 20:34:43

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 7499

Temperature: 92.9 °C
(93.3 ± 3.0 °C)

Apply Pressure: 591 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.428 Sec

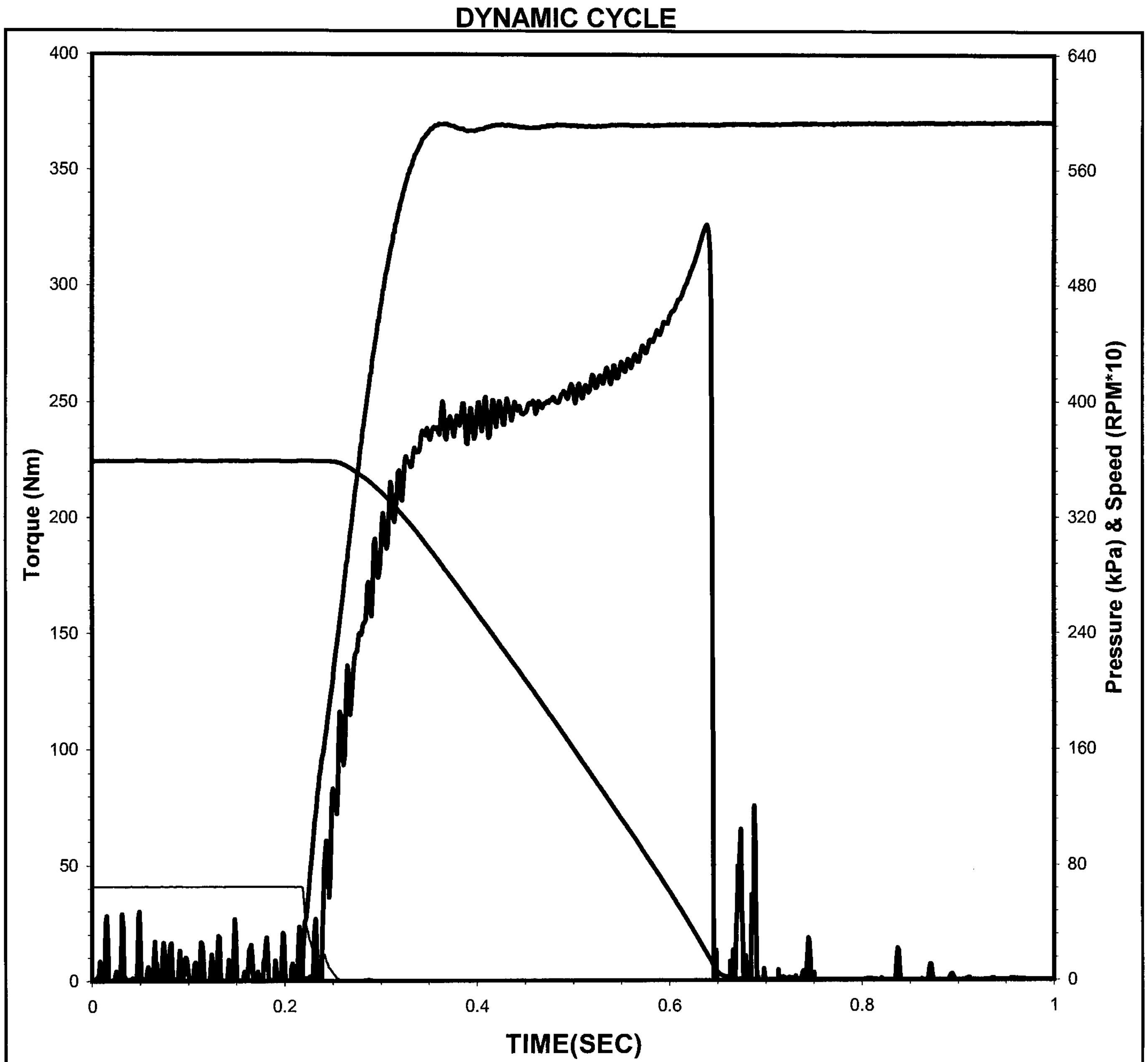
Torque

0.2 Sec Dyn: 244 N*m
Midpoint Dyn: 245 N*m
LwSpd Dynamic: 322 N*m

Coefficient of Friction

.2 Sec Dyn: 0.119
Midpoint Dyn: 0.119
LwSpd Dynamic: 0.157

ALLISON C-4 PAPER DATA



Date of Test:	7/20/2010
Time of Test:	20:34:58
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	7500
Temperature:	92.5 °C (93.3 ± 3.0 °C)
Apply Pressure:	591 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.427 Sec

Torque

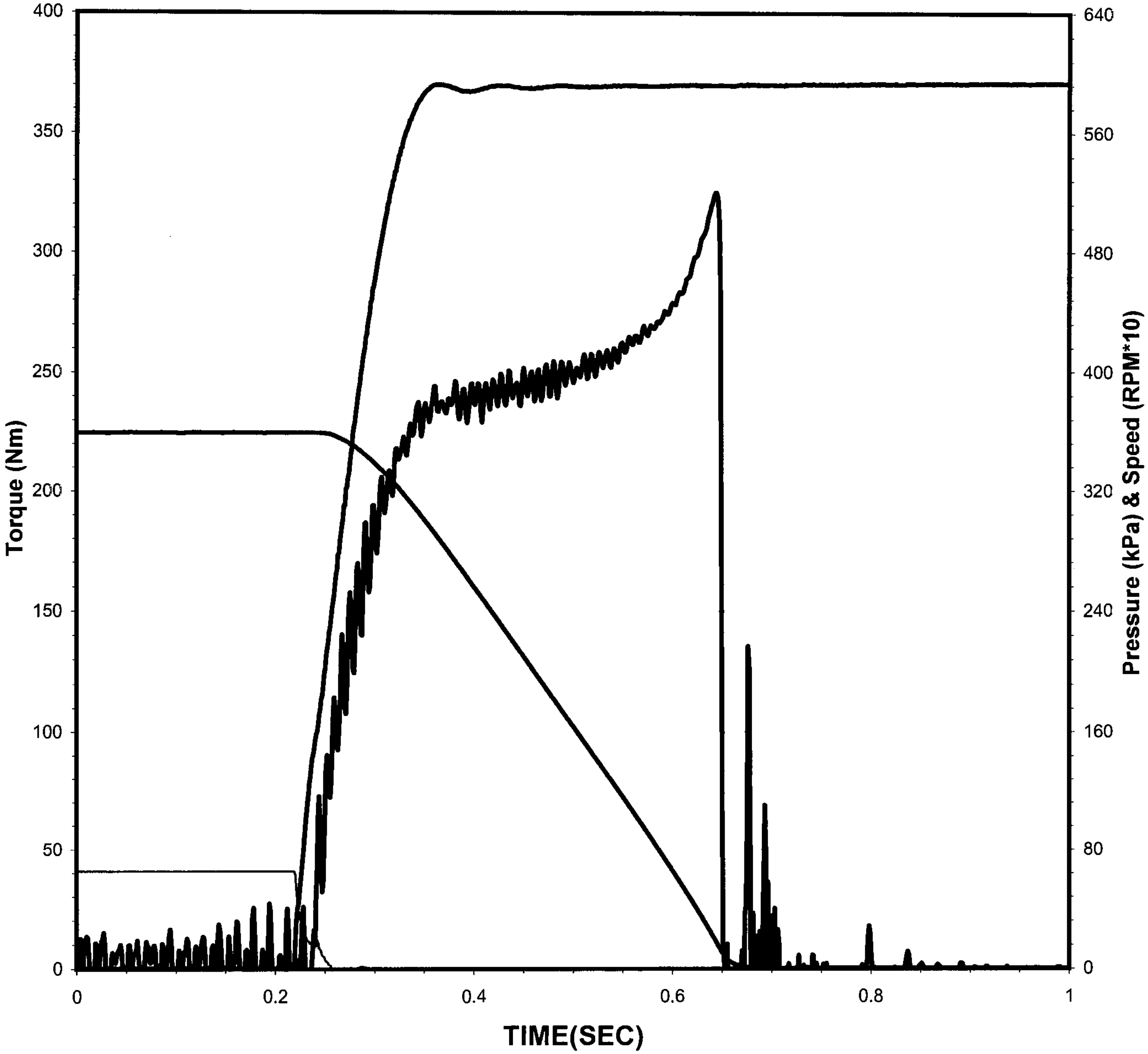
0.2 Sec Dyn:	244 N*m
Midpoint Dyn:	246 N*m
LwSpd Dynamic:	315 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.153

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/20/2010**
Time of Test:	**20:35:29**
Test Number:	**C2-5-1550**
Fluid Code:	**LO250033**
Cycle Number:	**7501**
Temperature:	**86.7 °C**
	(93.3 ± 3.0 °C)
Apply Pressure:	**590 kPa**
	(586 ± 7 KPa)
Apply Rate:	**0.13 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.6 KJ**
	(18.7 ± 0.40 KJ)
Engage Time:	**0.432 Sec**

Torque

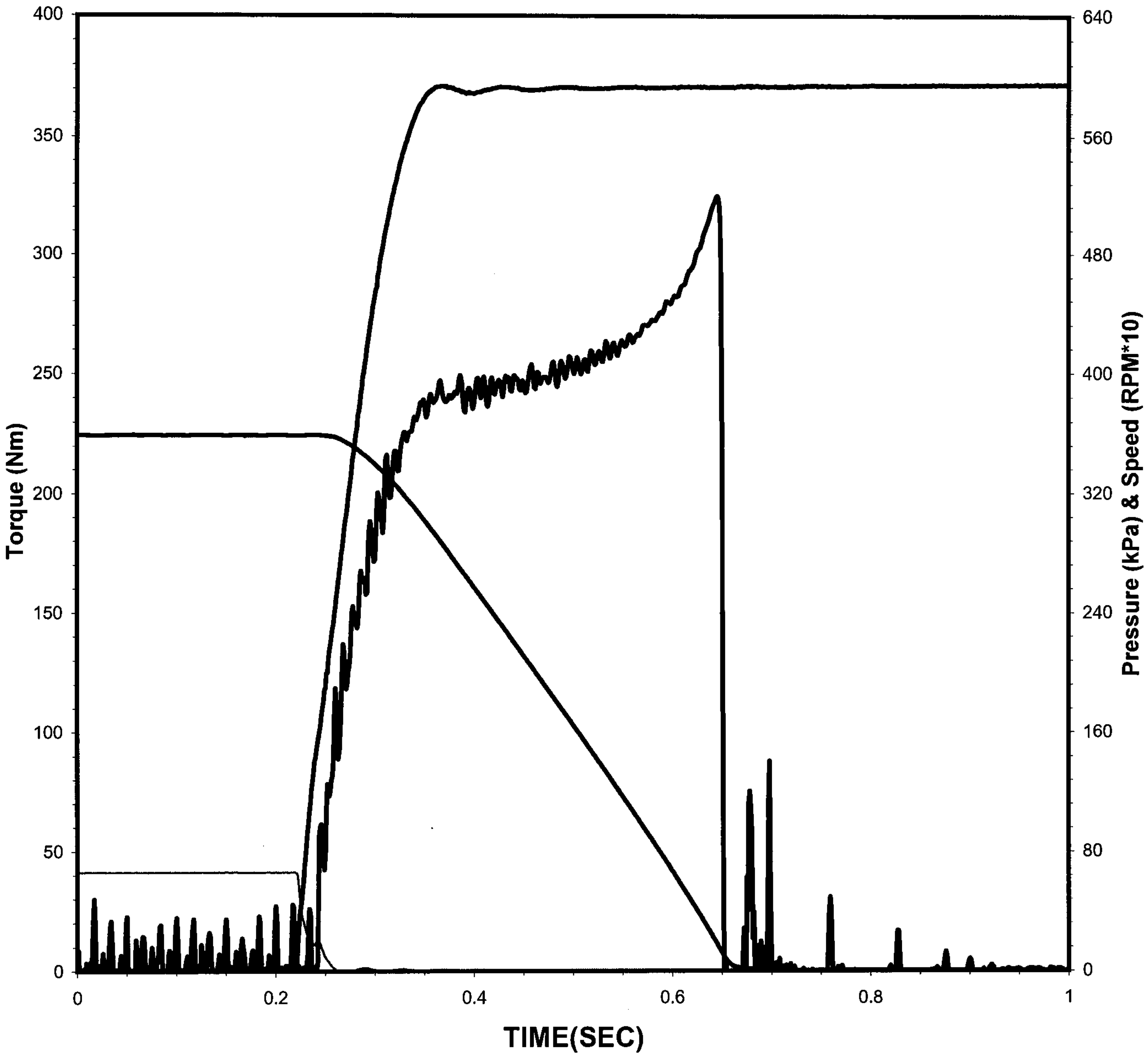
0.2 Sec Dyn:	**242 N*m**
Midpoint Dyn:	**243 N*m**
LwSpd Dynamic:	**312 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.118**
Midpoint Dyn:	**0.118**
LwSpd Dynamic:	**0.152**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/21/2010**
Time of Test:	**6:59:44**
Test Number:	**C2-5-1550**
Fluid Code:	**LO250033**
Cycle Number:	**9998**
Temperature:	**92.7 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**592 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.8 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.43 Sec**

Torque

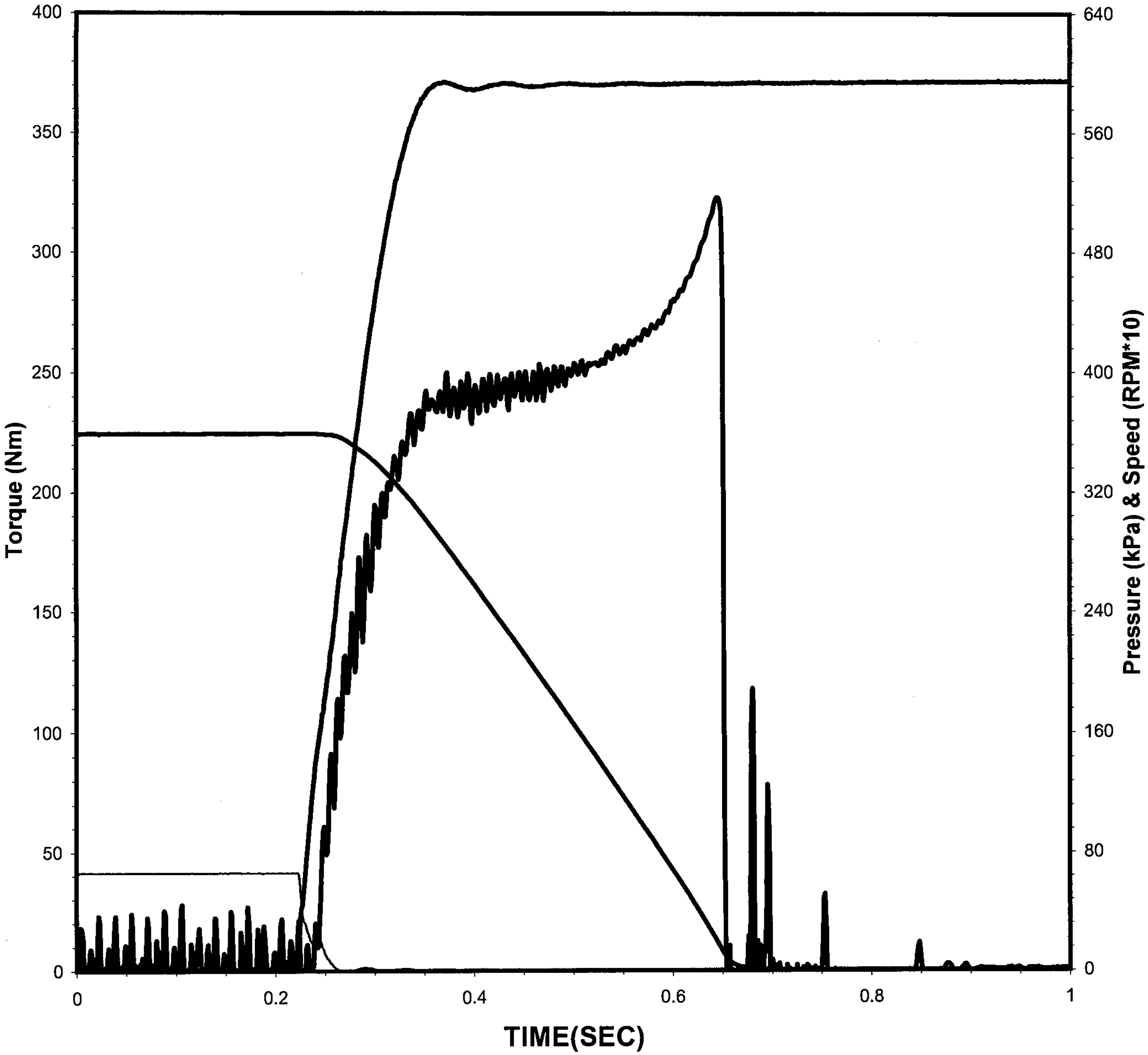
0.2 Sec Dyn:	**244 N*m**
Midpoint Dyn:	**245 N*m**
LwSpd Dynamic:	**313 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.119**
Midpoint Dyn:	**0.119**
LwSpd Dynamic:	**0.152**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/21/2010**
Time of Test:	**6:59:59**
Test Number:	**C2-5-1550**
Fluid Code:	**LO250033**
Cycle Number:	**9999**
Temperature:	**92.7 °C**
	(93.3 ± 3.0 °C)
Apply Pressure:	**592 kPa**
	(586 ± 7 KPa)
Apply Rate:	**0.13 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.6 KJ**
	(18.7 ± 0.40 KJ)
Engage Time:	**0.43 Sec**

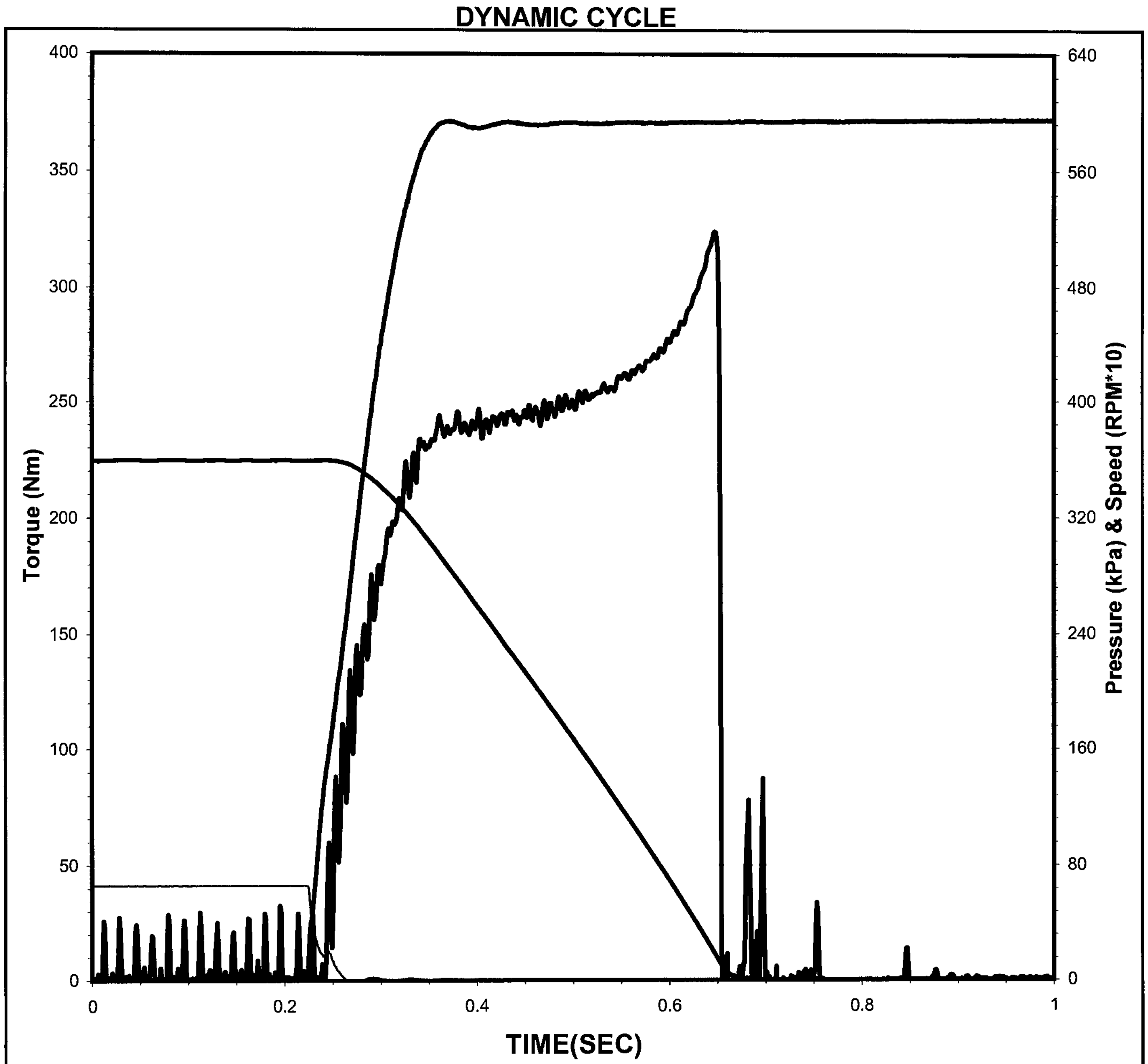
Torque

0.2 Sec Dyn:	**243 N*m**
Midpoint Dyn:	**243 N*m**
LwSpd Dynamic:	**318 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.118**
Midpoint Dyn:	**0.118**
LwSpd Dynamic:	**0.155**

ALLISON C-4 PAPER DATA



Date of Test:	7/21/2010
Time of Test:	7:00:15
Test Number:	C2-5-1550
Fluid Code:	LO250033
Cycle Number:	10000
Temperature:	92.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	592 kPa (586 ± 7 KPa)
Apply Rate:	0.14 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.429 Sec

Torque

0.2 Sec Dyn:	242 N*m
Midpoint Dyn:	243 N*m
LwSpd Dynamic:	316 N*m

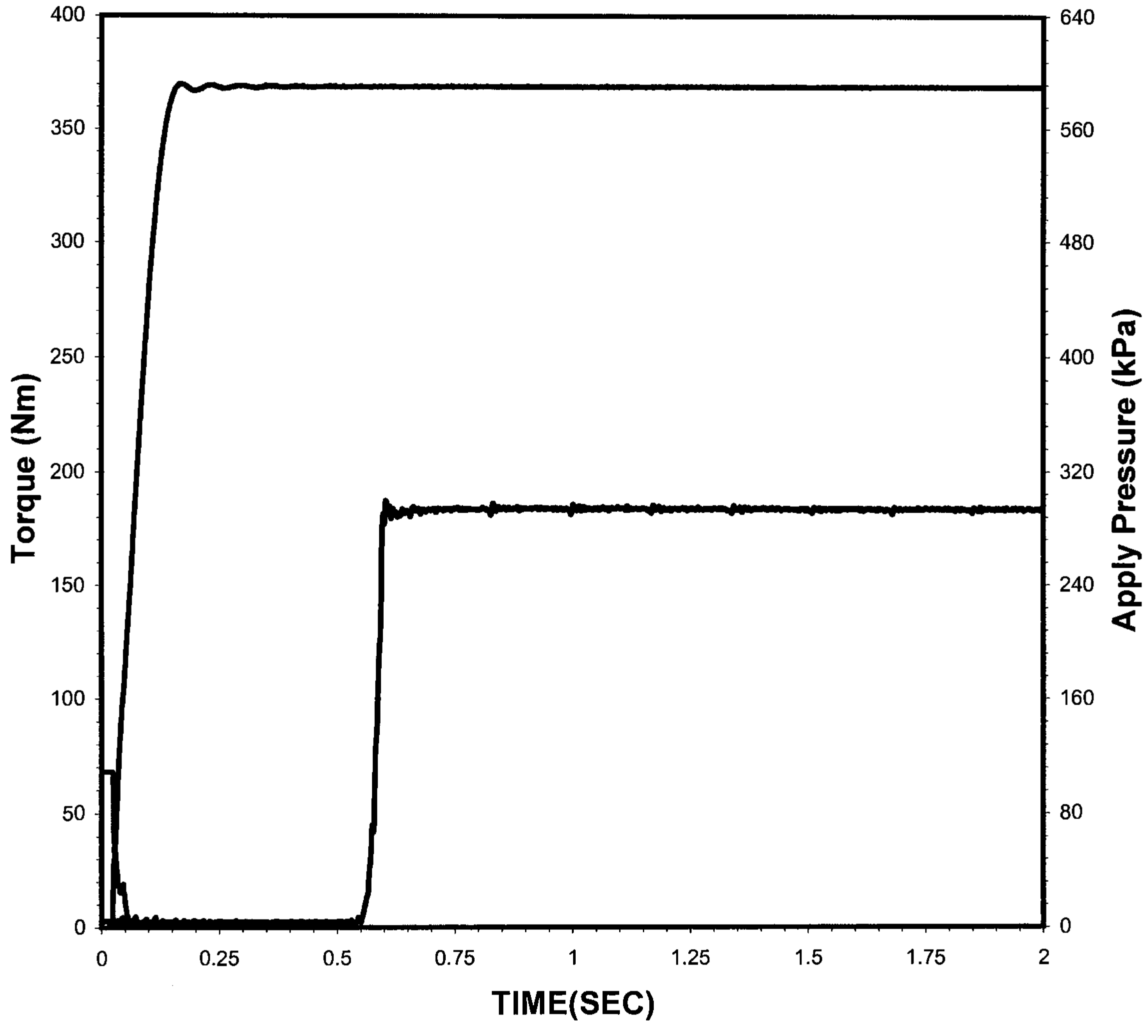
Coefficient of Friction

.2 Sec Dyn:	0.118
Midpoint Dyn:	0.118
LwSpd Dynamic:	0.154

STATIC TRACES

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/19/2010

Time of Test: 13:21:06

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 10

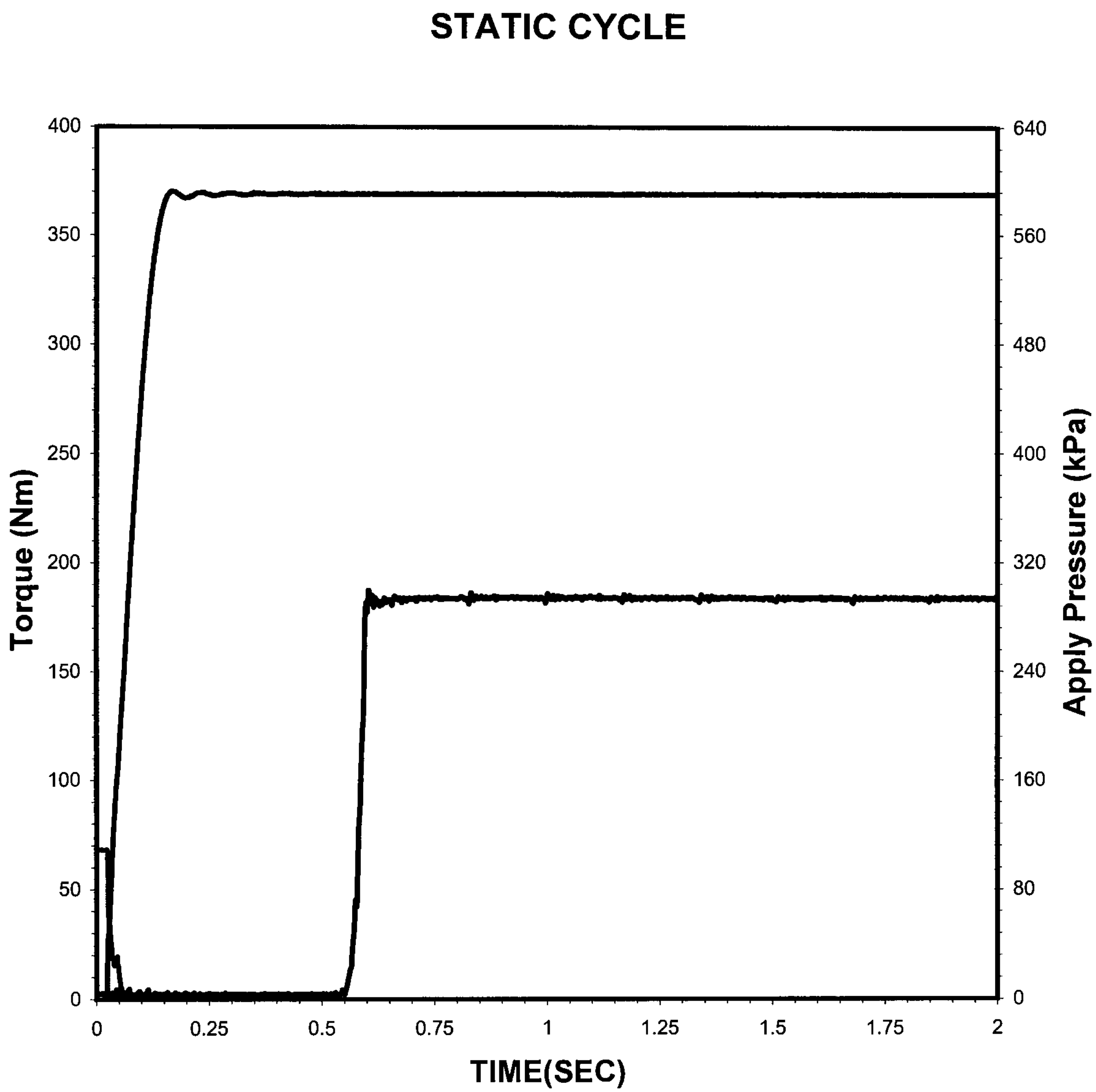
STATIC CYCLE

Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 397 Nm
.25 Second: 375 Nm

Coefficient of Friction
Static Peak: 0.194
.25 Second: 0.183

ALLISON C-4 PAPER DATA



Date of Test: 7/19/2010

Time of Test: 13:43:53

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 100

STATIC CYCLE

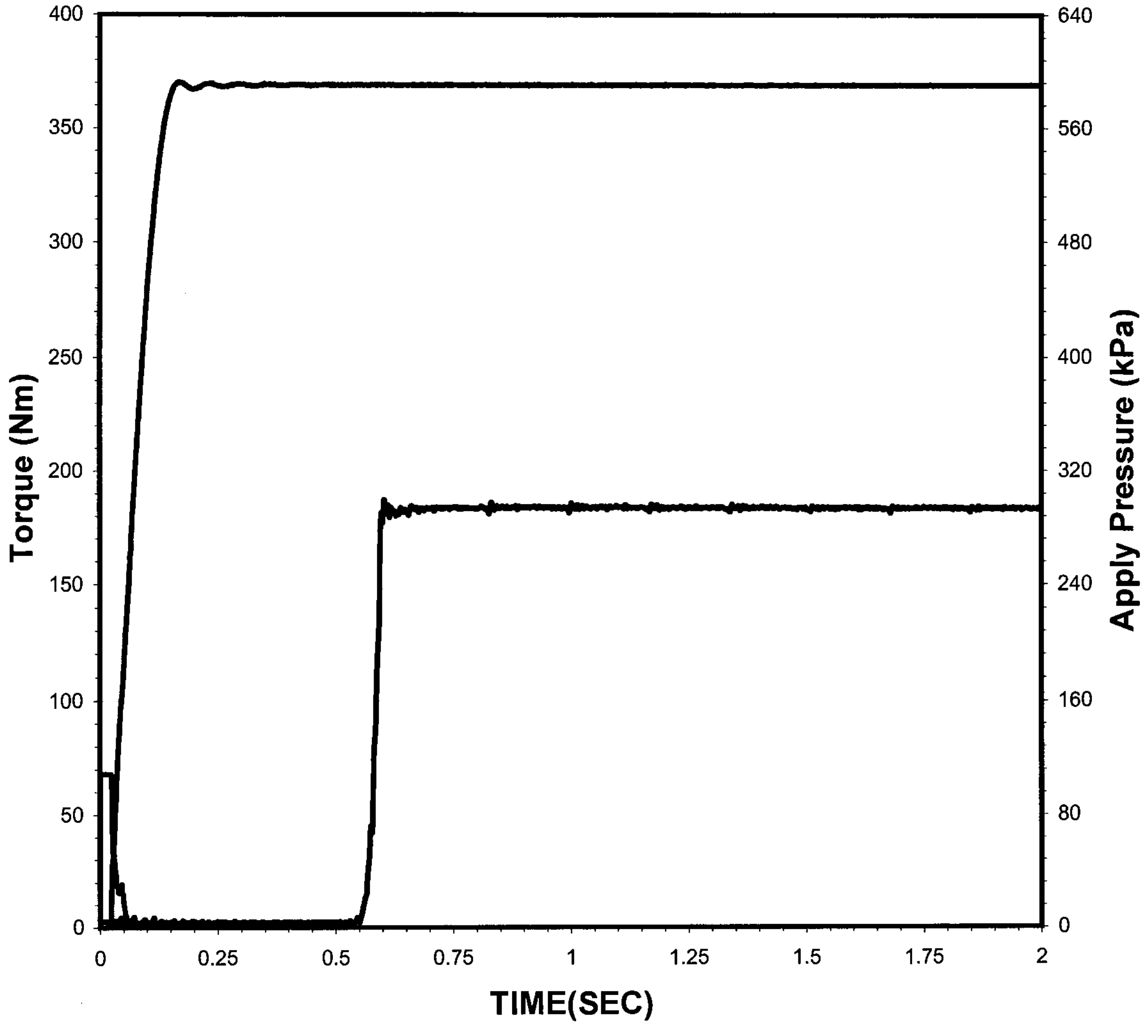
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 390 Nm
.25 Second: 375 Nm

Coefficient of Friction
Static Peak: 0.190
.25 Second: 0.183

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/19/2010

Time of Test: 15:24:09

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 500

STATIC CYCLE

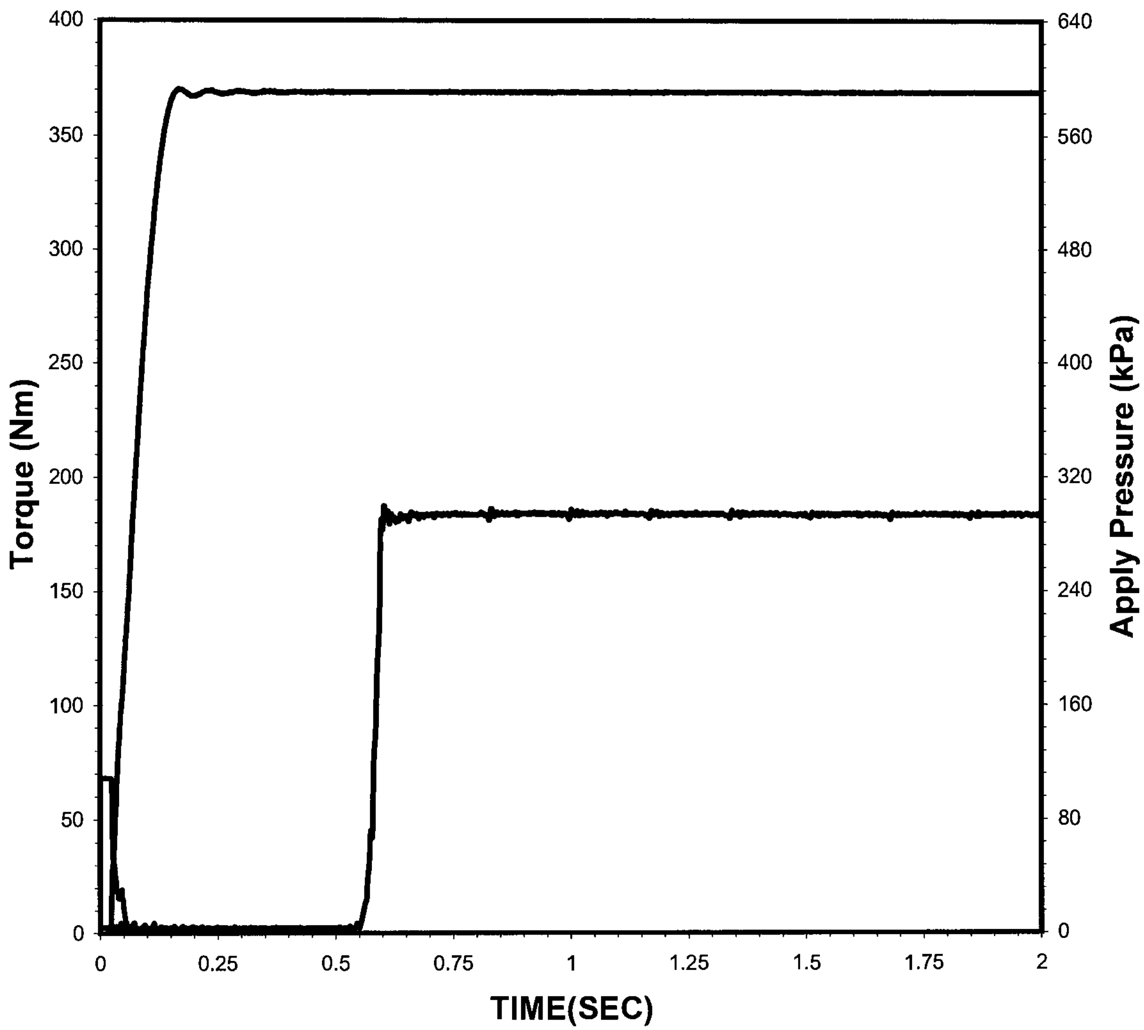
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 393 Nm
.25 Second: 375 Nm

Coefficient of Friction
Static Peak: 0.191
.25 Second: 0.183

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/19/2010

Time of Test: 17:29:25

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 1000

STATIC CYCLE

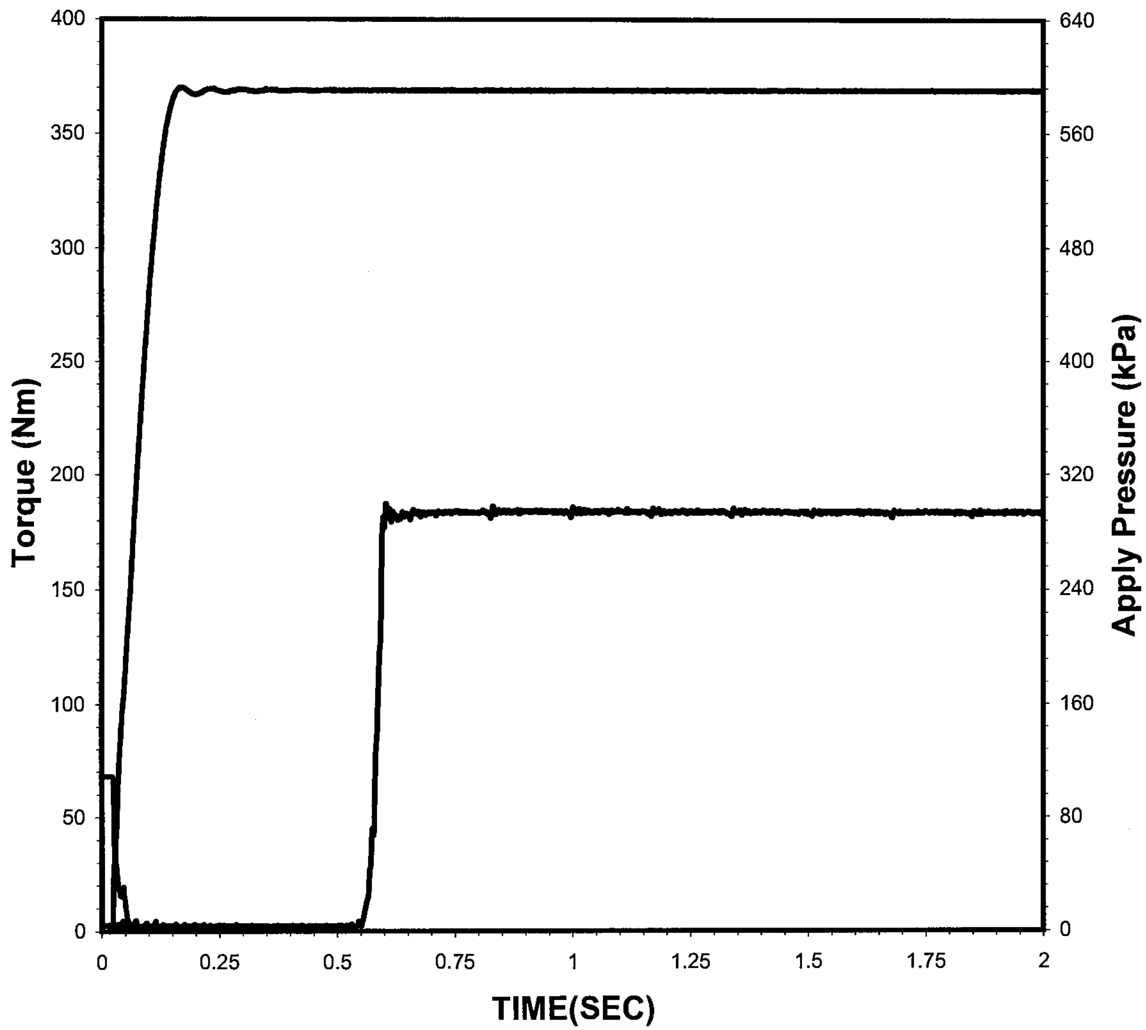
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 378 Nm
.25 Second: 366 Nm

Coefficient of Friction
Static Peak: 0.184
.25 Second: 0.178

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/19/2010

Time of Test: 23:44:42

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 2500

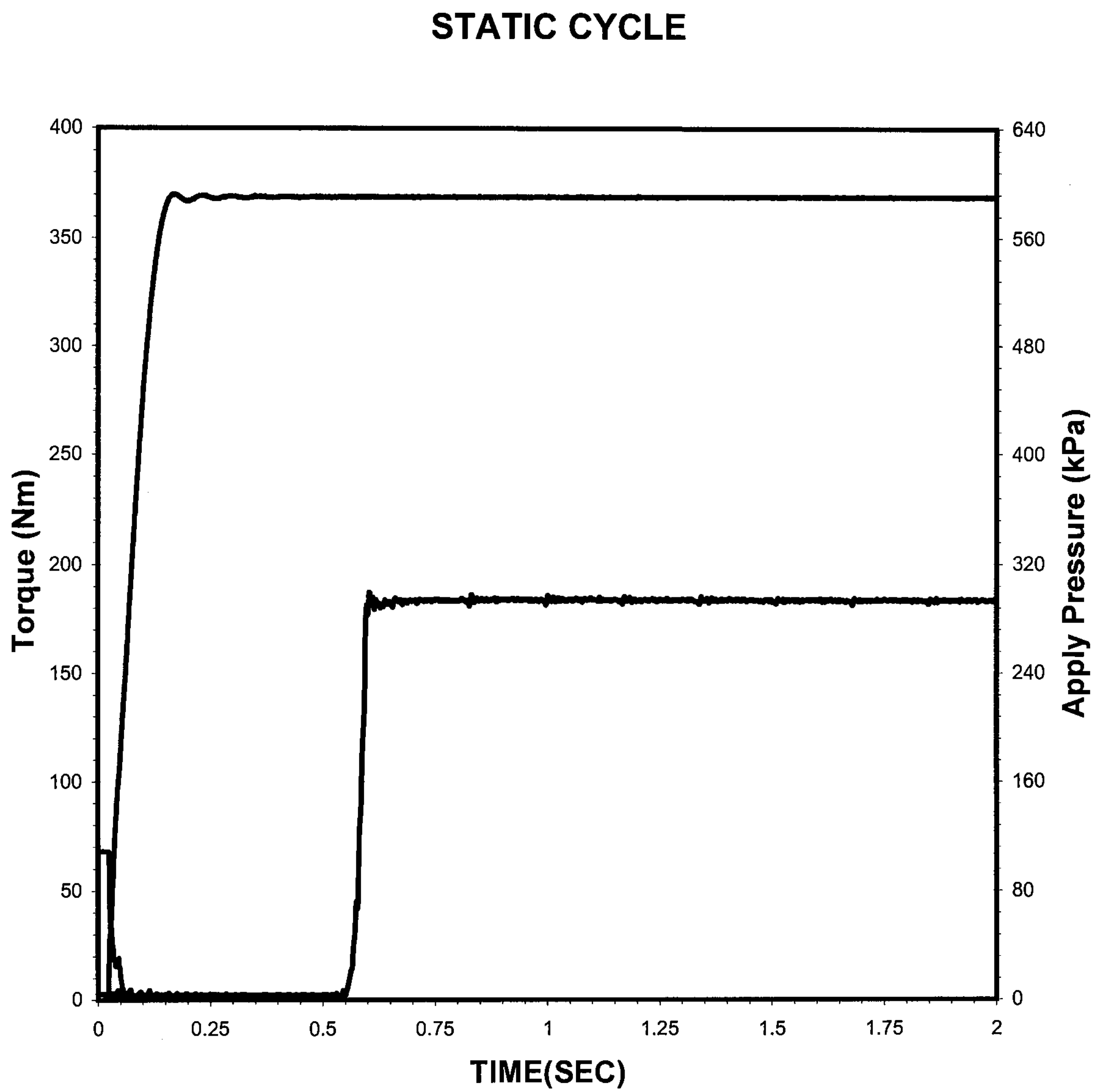
STATIC CYCLE

Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 358 Nm
.25 Second: 348 Nm

Coefficient of Friction
Static Peak: 0.174
.25 Second: 0.170

ALLISON C-4 PAPER DATA



Date of Test: 7/20/2010

Time of Test: 10:09:58

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 5000

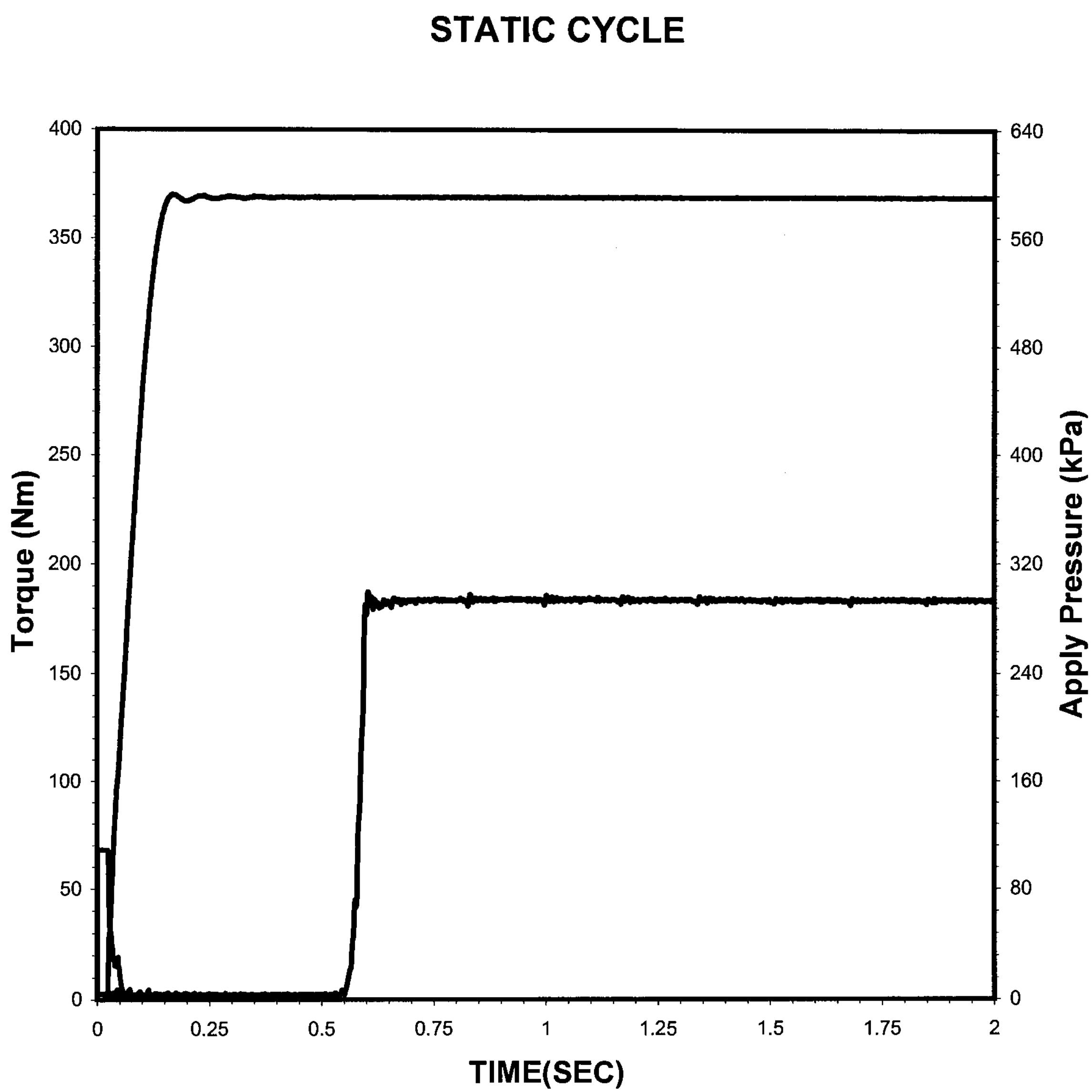
STATIC CYCLE

Apply Pressure:
At .25 Second: 592 kPa

Torque
Static Peak: 355 Nm
.25 Second: 341 Nm

Coefficient of Friction
Static Peak: 0.173
.25 Second: 0.166

ALLISON C-4 PAPER DATA



Date of Test: 7/20/2010

Time of Test: 20:35:14

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 7500

STATIC CYCLE

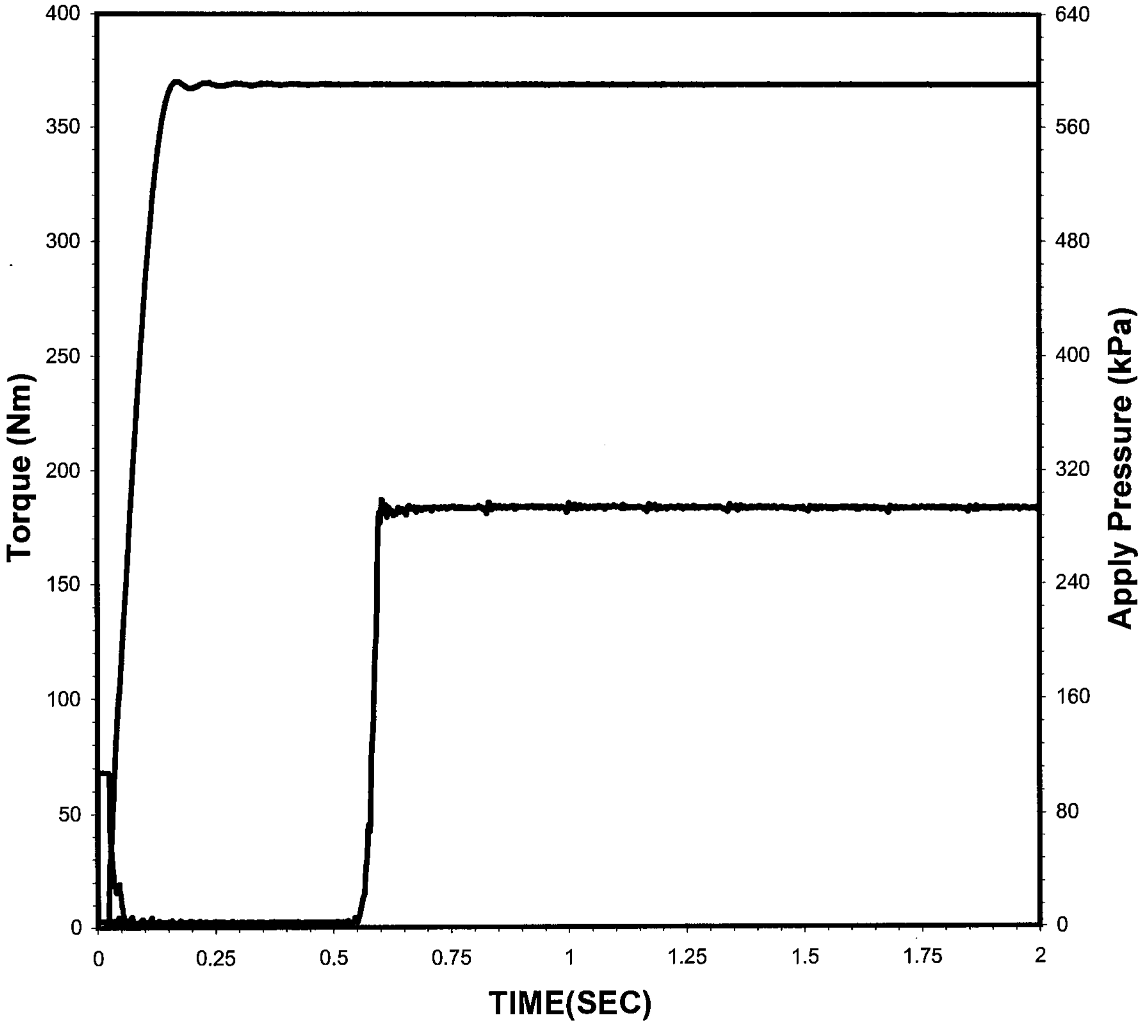
Apply Pressure:
At .25 Second: 591 kPa

Torque
Static Peak: 355 Nm
.25 Second: 339 Nm

Coefficient of Friction
Static Peak: 0.173
.25 Second: 0.165

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 7:00:31

Test Number: C2-5-1550

Fluid Code: LO250033

Cycle Number: 10000

STATIC CYCLE

Apply Pressure:
At .25 Second: 592 kPa

Torque
Static Peak: 344 Nm
.25 Second: 335 Nm

Coefficient of Friction
Static Peak: 0.167
.25 Second: 0.163

C4 SEAL TEST SUMMARY SHEET

Test Sponsor: SOUTHWEST RESEARCH INSTITUTE

Oil Code: 250033
Secondary Code:
Test Key:
SwRI Code: 488554
Date: 20100810

Elastomer	Candidate			Average	MILPRF2104G Batch 12-06	Limits
V1 A-7-0060-85-ETI						
Volume Change, %	8.58	8.59	8.55	8.57	15.25	0.00 to 20.00
Hardness Change, pts.	-3	-3	-2	-3	-6	-15 to 0
V2 P-250						
Volume Change, %	5.83	5.87	5.42	5.71	8.59	0.00 to 12.00
Hardness Change, pts.	1	0	1	1	-1	-7 to 3
V3 FM-L-69						
Volume Change, %	8.94	8.91	8.99	8.94	15.84	0.00 to 22.00
Hardness Change, pts.	-4	-5	-4	-4	-7	-14 to 0
P1 A-6-0160-85-ETI						
Volume Change, %	2.66	2.73	2.74	2.71	4.33	0.00 to 8.00
Hardness Change, pts.	-2	-2	-2	-2	-4	-10 to 0
P2 GR-A2256						
Volume Change, %	4.53	4.63	4.76	4.64	6.88	0.00 to 8.00
Hardness Change, pts.	-1	0	-1	-1	-2	-11 to 3
P3 6830						
Volume Change, %	0.14	0.39	0.44	0.32	2.00	0.00 to 4.00
Hardness Change, pts.	1	1	2	1	-1	-8 to 4
F1 7V2127						
Volume Change, %	0.81	0.82	0.83	0.82	0.97	0.00 to 3.00
Hardness Change, pts.	1	0	0	0	0	-5 to 4
F2 V150						
Volume Change, %	0.99	1.16	1.11	1.08	1.49	0.00 to 4.00
Hardness Change, pts.	0	0	0	0	0	-2 to 5
N1 GR-N1386						
Volume Change, %	-2.94	-3.07	-3.01	-3.01	0.37	0.00 to 5.00
Hardness Change, pts.	8	7	7	7	6	-12 to 12
N2						
Volume Change, %						0.00 to 6.00
Hardness Change, pts.						-9 to 5

Rebecca D. Grinfield

Rebecca D. Grinfield
Sr. Research Scientist

APPENDIX D4. – EVAULATION OF CANDIDATE LO251746 IN ALLISON C4 TRANSMISSION TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 GRAPHITE CLUTCH FRICTION TEST

Conducted For

ARMY LAB

Oil Code:
LO251746

Test Number:
C4-7-1285

July 21, 2010

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

Allison C-4 Heavy Duty Transmission Fluid Specification	Allison Transmission

VIII. Graphite Clutch Friction Test

Test Laboratory:	SWRI	Lab Fluid Code:	LO-251746
Test Number:	C4-7-1285	Sponsor Fluid Code:	LO251746
Friction Plate Batch:	BATCH 44	Completion Date:	7/21/2010
Steel Plate Batch:	10/9/2008		

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0760	0.0668

	Before	After
Pack Clearance	0.5334	0.6096

Reference Tests

Test Number	Test Date	Test Fluid
C4-0-1257	11/25/09	PASS REF-L-06-04
C4-0-1267	01/08/10	PASS REF-L-06-04
C4-0-1278	05/26/10	PASS REF-L-06-04

	New	EOT
Viscosity at 40°C, cSt	42.87	37.54
Viscosity at 100°C, cSt	8.12	7.36
Iron Content, ppm	2	62

D5185	New Fluid (ppm)
Ba	<1
B	69
Ca	792
Mg	1170
P	1046
Si	5
Na	5
Zn	1230

Name: Matt Jackson

Signature:

Title: Manager

Date: 7/30/10

ALLISON C-4 GRAPHITE FRICTION TEST SUMMARY

(Torque in Ft-Lbs)

Sponsor Fluid Code:	**LO251746**	Test Number:	**C4-7-1285**
Lab Fluid Code:	**LO-251746**	Fric. Plate Batch:	**Batch 44**
Completion Date:	**7/21/2010**	Steel Plate Batch:	**10/9/2008**

PHASE A

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
500	1.40	41	75	27	48	83	75
1000	1.64	32	72	22	50	87	73

PHASE B

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	TORQUE (0.2 Second)	STATIC PEAK - 0.2 TORQUE	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
1500	0.81	96	152	77	75	171	159
2000	0.88	88	150	62	88	161	158
2500	0.90	86	149	56	93	168	157
3500	0.96	81	148	47	101	162	155
4000	0.96	81	146	47	99	167	154
4500	0.96	81	147	45	102	173	153
5000	0.96	82	145	45	100	165	153
5500	0.90	90	145	51	94	163	152

	Limits		Results			
	Max	Max Change	1,500 N	5,500 N	% Change	P/F
Slip Time Max.	0.89	N/A	0.81	0.90	11.11	F
0.2 Second Dynamic Coeff.	N/A	N/A	0.072	0.048	-33.333	
Mid-Point Fric. Coeff. Min.	0.089	N/A	0.090	0.084	-6.667	F
Static Friction Coeff.	N/A	N/A	0.142	0.136	-4.225	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.160	0.153	-4.375	
0.25 Second Low Speed Coeff.	N/A	N/A	0.149	0.142	-4.698	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-GRAPHITE FRICTION TEST

Candidate Fluid: LO251746 **Test Number : C4-7-1285** **Completion Date : 7/21/2010**

Lab Fluid Code : LO-251746 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 44**

(all units in mm)

Plates	Location of Tooth (Clockwise)	Near Inner Diameter		Near Outer Diameter		Inner Diameter Change	Average Overall Change	Outer Diameter Change
		Before	After	Before	After			
FRICTION MATERIAL								
2	Top	2.2450	2.1770	2.2440	2.1820	0.0680		0.0620
	120	2.2460	2.1700	2.2450	2.1820	0.0760		0.0630
	240	2.2500	2.1800	2.2520	2.1900	0.0700		0.0620
	Average					0.0713	0.0668	0.0623
STEEL SEPARATORS								
1	Top	1.7530	1.7530	1.7530	1.7530	0.0000		0.0000
	120	1.7550	1.7550	1.7550	1.7550	0.0000		0.0000
	240	1.7550	1.7550	1.7560	1.7560	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7610	1.7610	1.7640	1.7640	0.0000		0.0000
	120	1.7600	1.7600	1.7580	1.7580	0.0000		0.0000
	240	1.7600	1.7600	1.7600	1.7600	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

PLATE CONDITION AT E.O.T. PLATES IN GOOD CONDITION

(Anything Unusual)

Test Date: 7/21/2010

Operator's Name: JOE M

Reviewed By (Signature and Date)

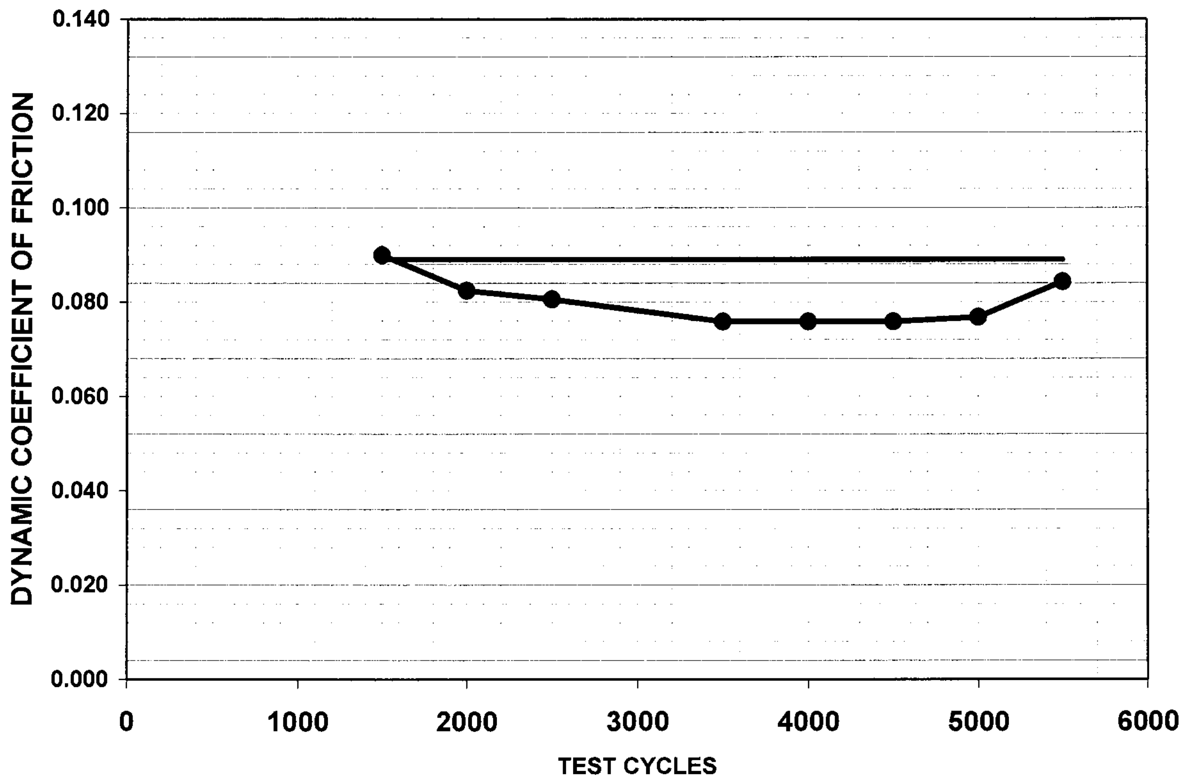
7/30/10

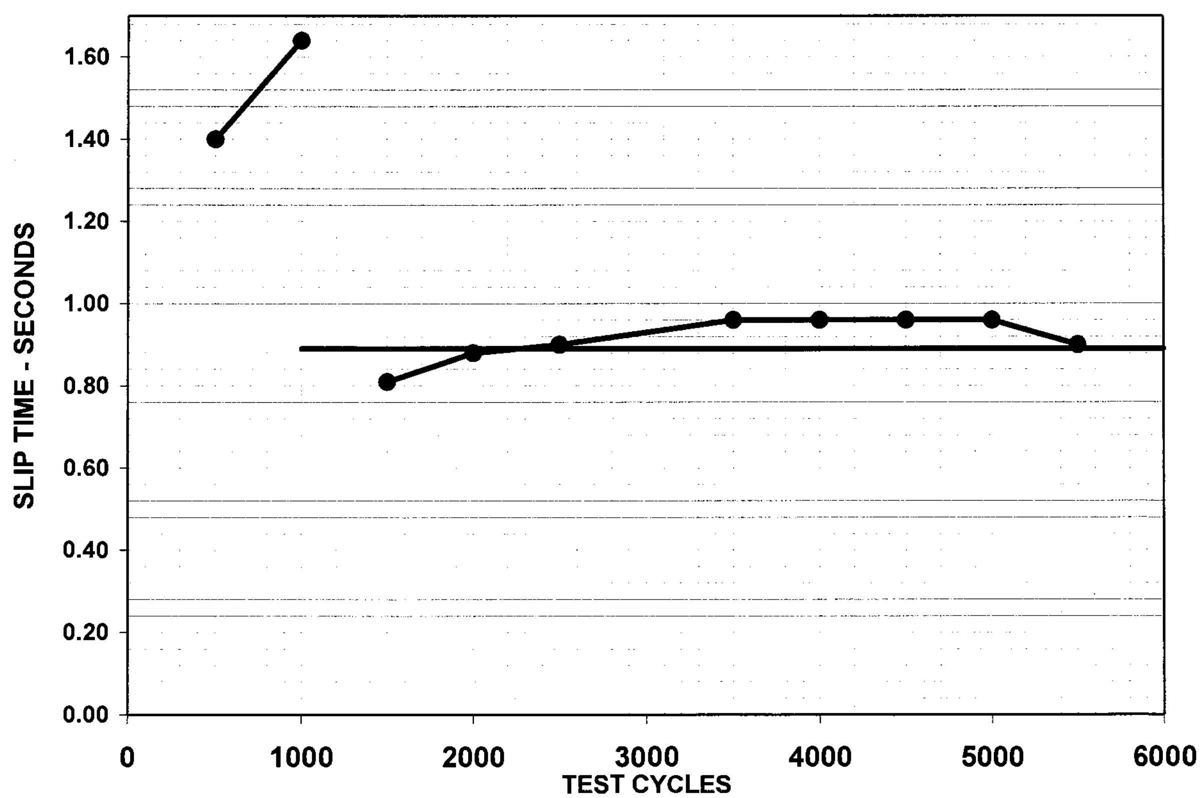
Pack ID#: 4419

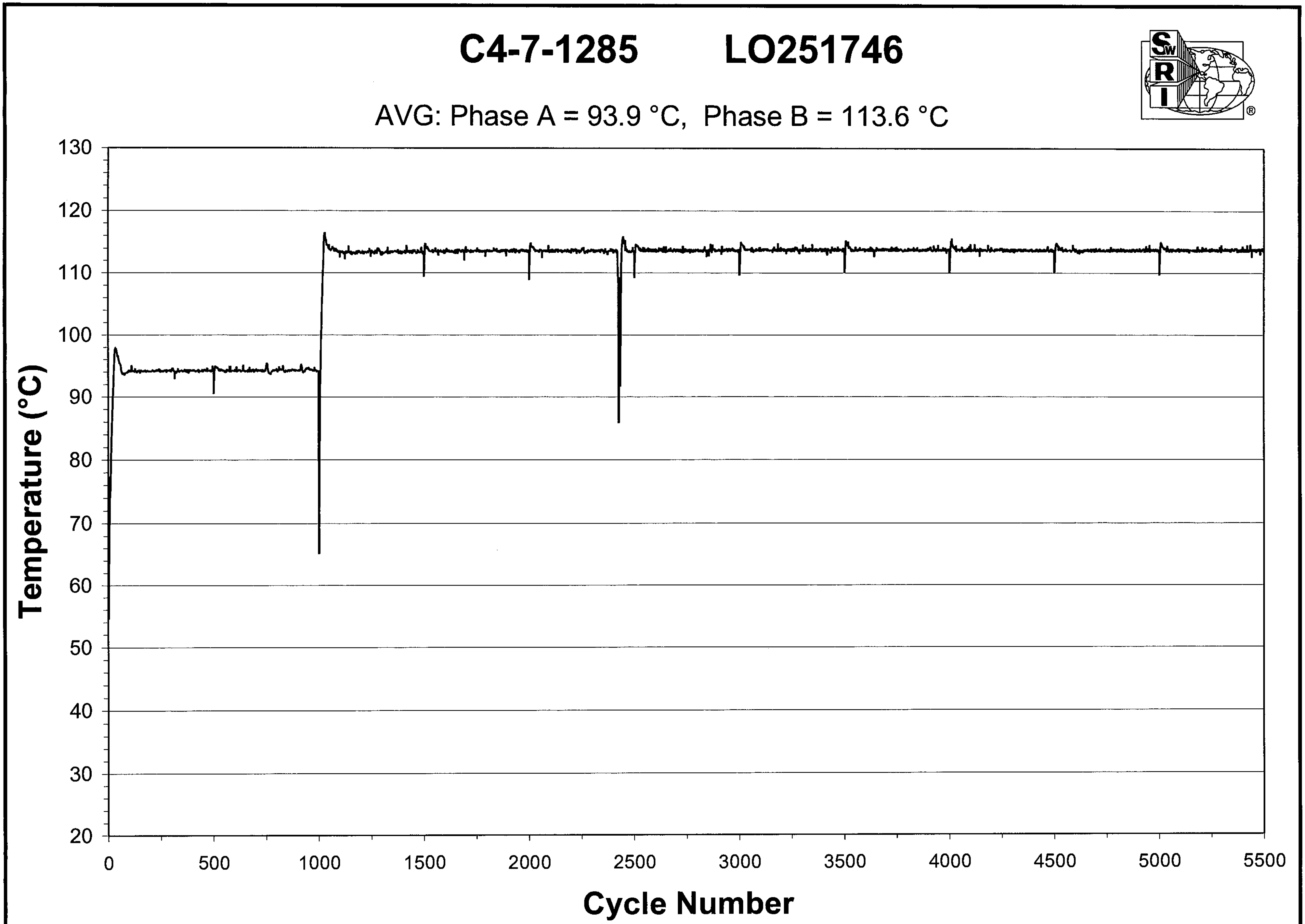
ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 GRAPHITE FRICTION TEST

EOT Date: 7/21/2010
Test Number: C4-7-1285

Fluid Code: LO251746
Plate Batch: Batch 44
Steel Batch: 10/9/2008



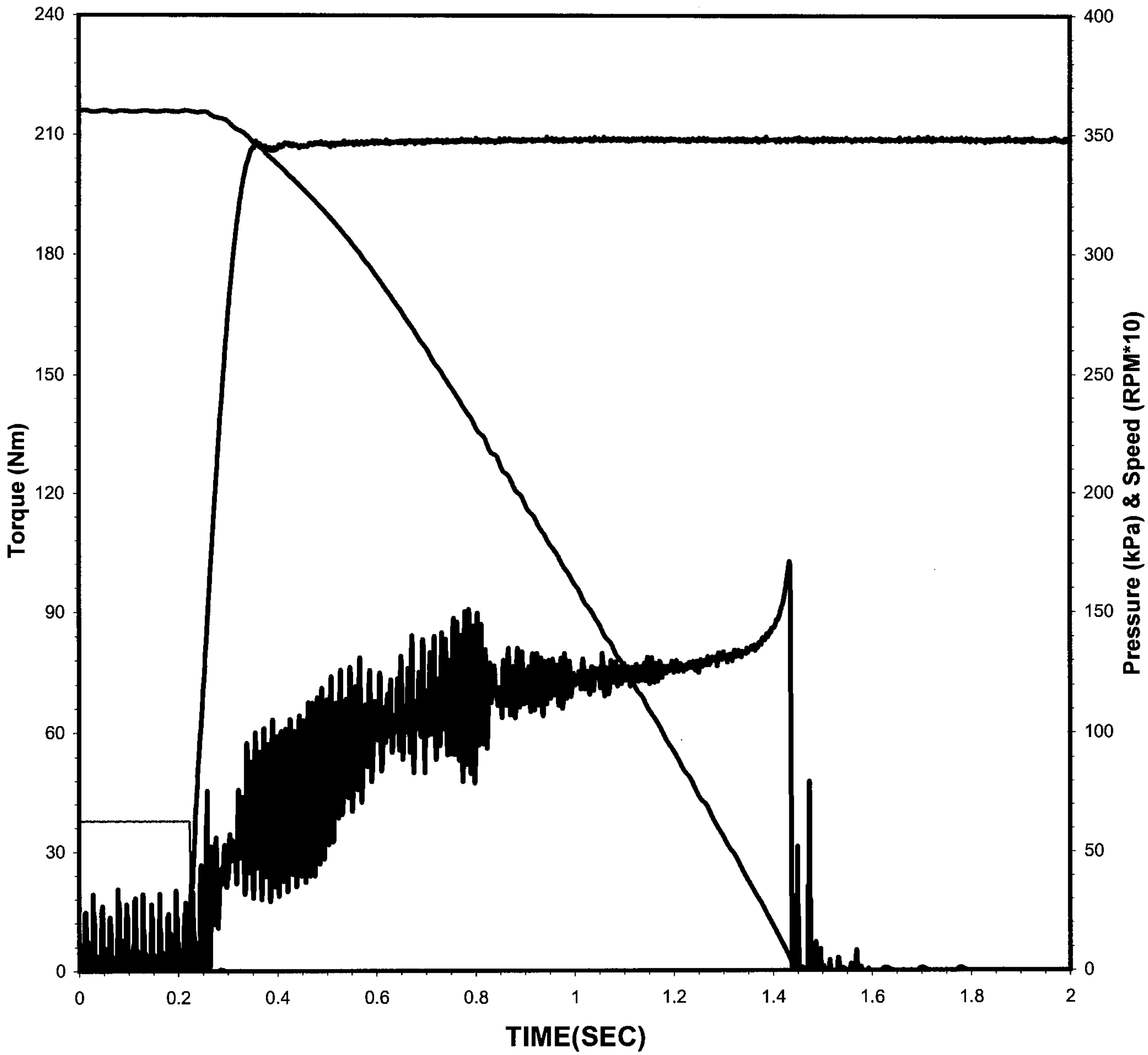



C4-7-1285 LO251746
AVG: Phase A = 93.9 °C, Phase B = 113.6 °C
130
120
110
100
90
80
70
60
50
40
30
20
Temperature (°C)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Cycle Number

DYNAMIC TRACES

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: **7/20/2010**

Time of Test: **12:30:33**

Test Number: **C4-7-1285**

Fluid Code: **LO251746**

Cycle Number: **10**

Temperature: **77.4 °C**
(93.3 ± 3.0 °C)

Apply Pressure: **348 kPa**
(345 ± 7 KPa)

Apply Rate: **0.12 Sec**
(0.15 ± 0.02 Sec)

Energy: **14.2 KJ**
(14.50 ± 0.40 KJ)

Engage Time: **1.214 Sec**

Torque

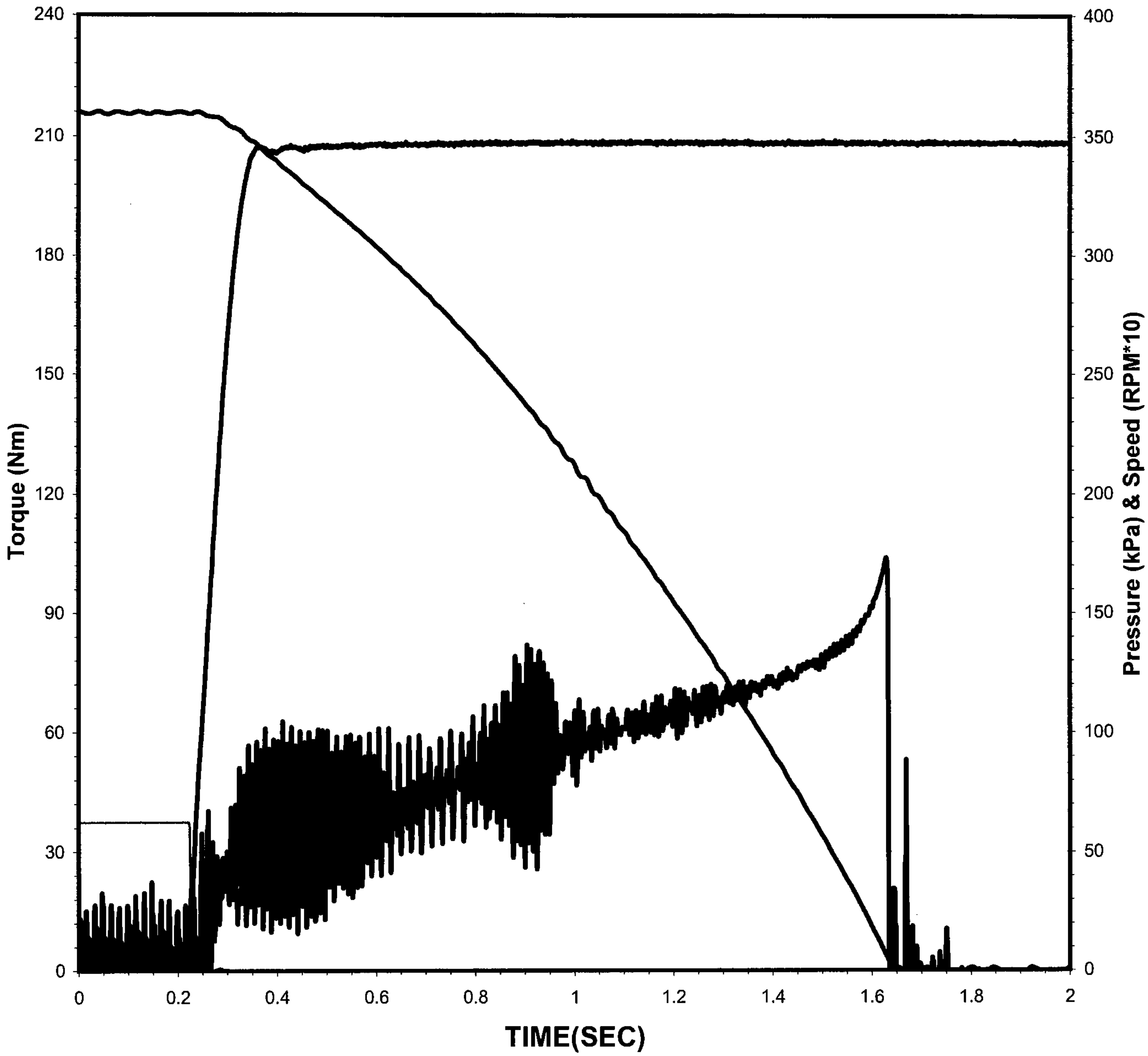
0.2 Sec Dyn:	**42 N*m**
Midpoint Dyn:	**71 N*m**
LwSpd Dynamic:	**103 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.069**
Midpoint Dyn:	**0.118**
LwSpd Dynamic:	**0.170**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	**7/20/2010**
Time of Test:	**14:33:00**
Test Number:	**C4-7-1285**
Fluid Code:	**LO251746**
Cycle Number:	**499**
Temperature:	**94.2 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**349 kPa** (345 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**14.1 KJ** (14.50 ± 0.40 KJ)
Engage Time:	**1.411 Sec**

Torque

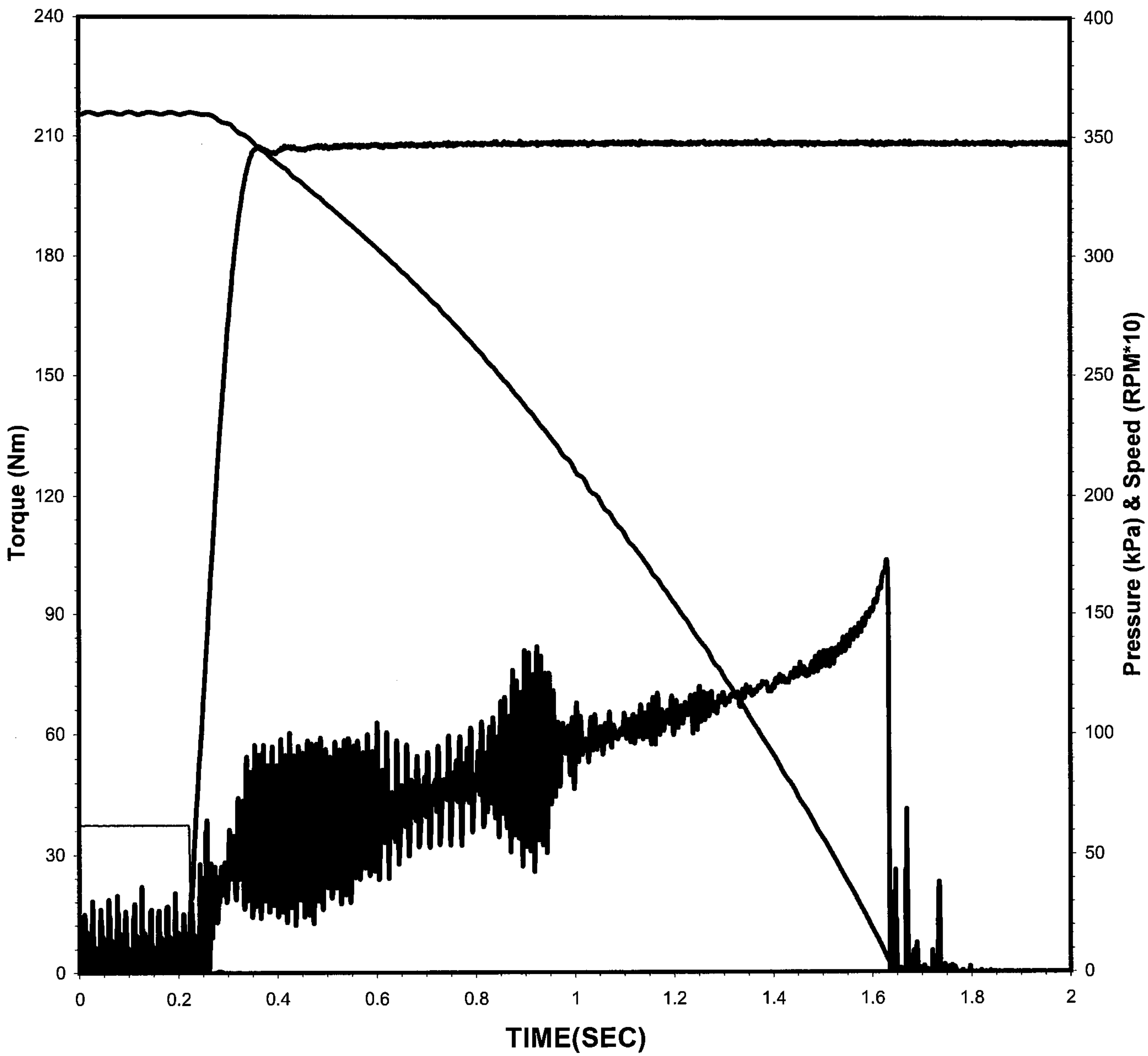
0.2 Sec Dyn:	**36 N*m**
Midpoint Dyn:	**55 N*m**
LwSpd Dynamic:	**102 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.060**
Midpoint Dyn:	**0.091**
LwSpd Dynamic:	**0.169**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/20/2010

Time of Test: 14:33:15

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 500

Temperature: 94.1 °C
(93.3 ± 3.0 °C)

Apply Pressure: 348 kPa
(345 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 14.1 KJ
(14.50 ± 0.40 KJ)

Engage Time: 1.412 Sec

Torque

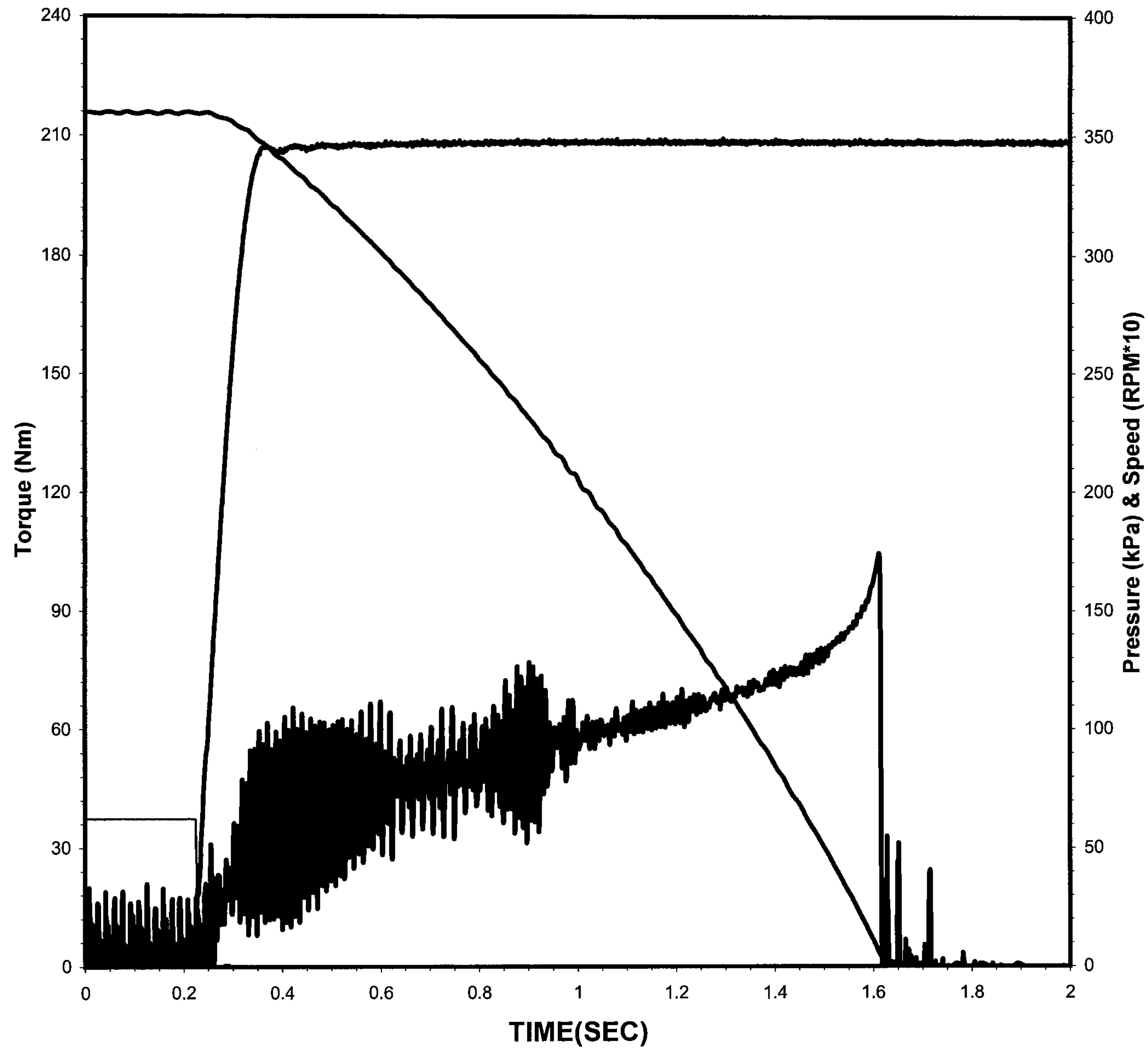
0.2 Sec Dyn:	35 N*m
Midpoint Dyn:	56 N*m
LwSpd Dynamic:	101 N*m

Coefficient of Friction

.2 Sec Dyn:	0.059
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.168

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/20/2010
Time of Test:	14:33:42
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	501
Temperature:	90.5 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	349 kPa
	(345 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	14.1 KJ
	(14.50 ± 0.40 KJ)
Engage Time:	1.391 Sec

Torque

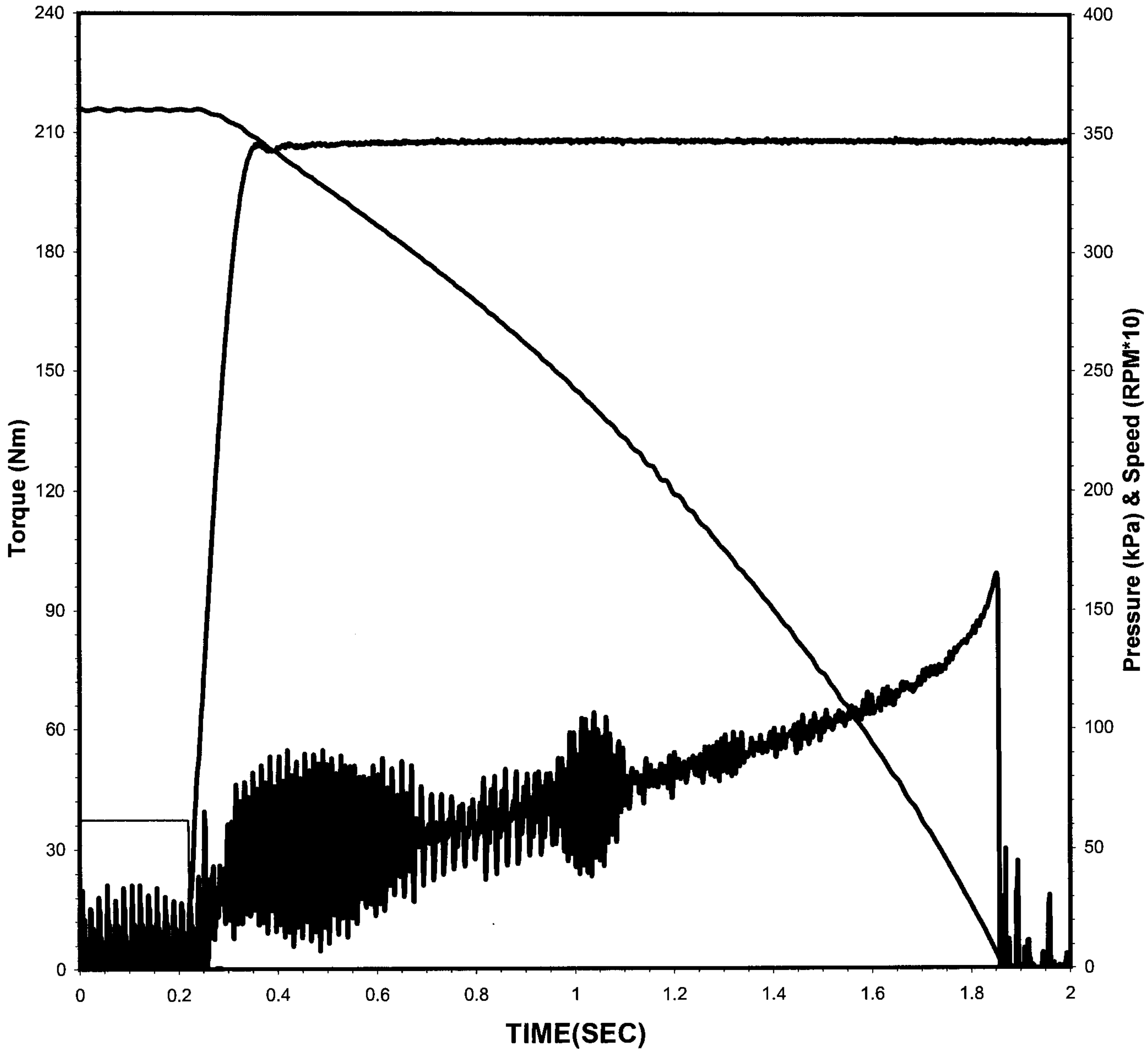
0.2 Sec Dyn:	39 N*m
Midpoint Dyn:	56 N*m
LwSpd Dynamic:	103 N*m

Coefficient of Friction

.2 Sec Dyn:	0.065
Midpoint Dyn:	0.093
LwSpd Dynamic:	0.171

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test: 7/20/2010

Time of Test: 16:37:57

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 998

Temperature: 94.2 °C
(93.3 ± 3.0 °C)

Apply Pressure: 349 kPa
(345 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 13.9 KJ
(14.50 ± 0.40 KJ)

Engage Time: 1.637 Sec

Torque

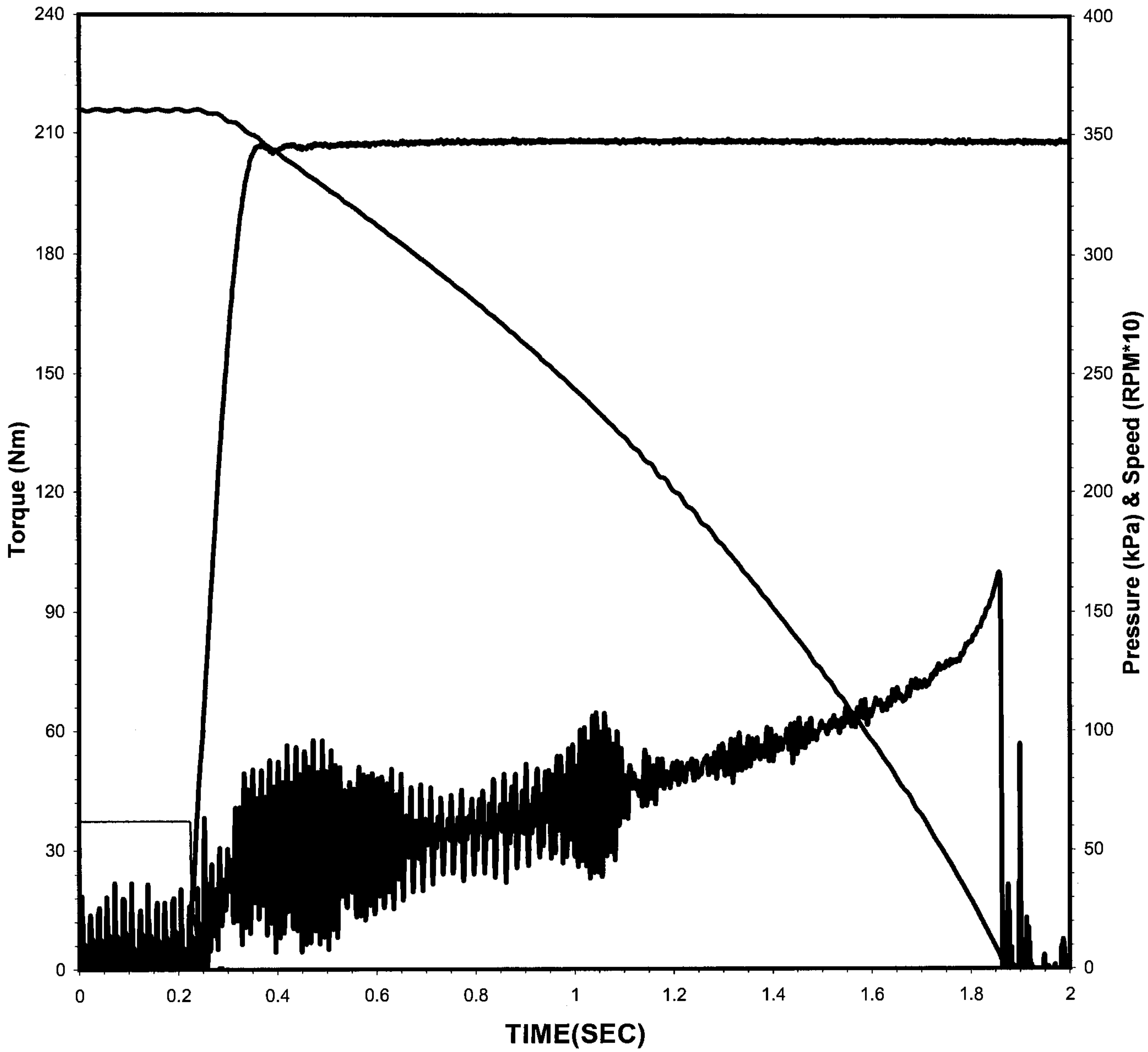
0.2 Sec Dyn:	**30 N*m**
Midpoint Dyn:	**43 N*m**
LwSpd Dynamic:	**98 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.050**
Midpoint Dyn:	**0.072**
LwSpd Dynamic:	**0.163**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/20/2010
Time of Test:	16:38:12
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	999
Temperature:	94.1 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	349 kPa
	(345 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	13.9 KJ
	(14.50 ± 0.40 KJ)
Engage Time:	1.638 Sec

Torque

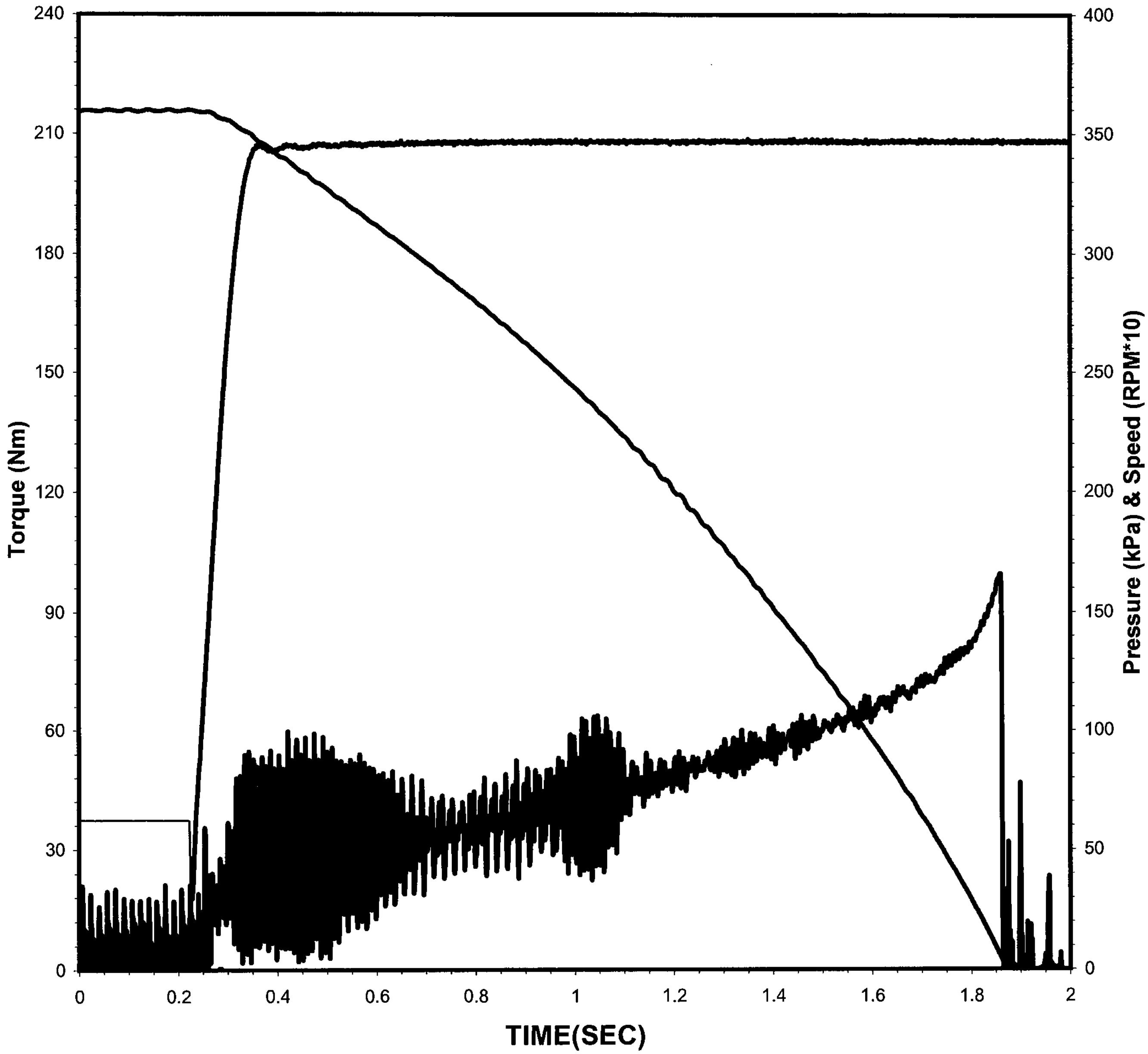
0.2 Sec Dyn:	30 N*m
Midpoint Dyn:	43 N*m
LwSpd Dynamic:	99 N*m

Coefficient of Friction

.2 Sec Dyn:	0.049
Midpoint Dyn:	0.072
LwSpd Dynamic:	0.164

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE A



Date of Test:	7/20/2010
Time of Test:	16:38:27
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	1000
Temperature:	94.2 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	349 kPa
	(345 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	13.8 KJ
	(14.50 ± 0.40 KJ)
Engage Time:	1.64 Sec

Torque

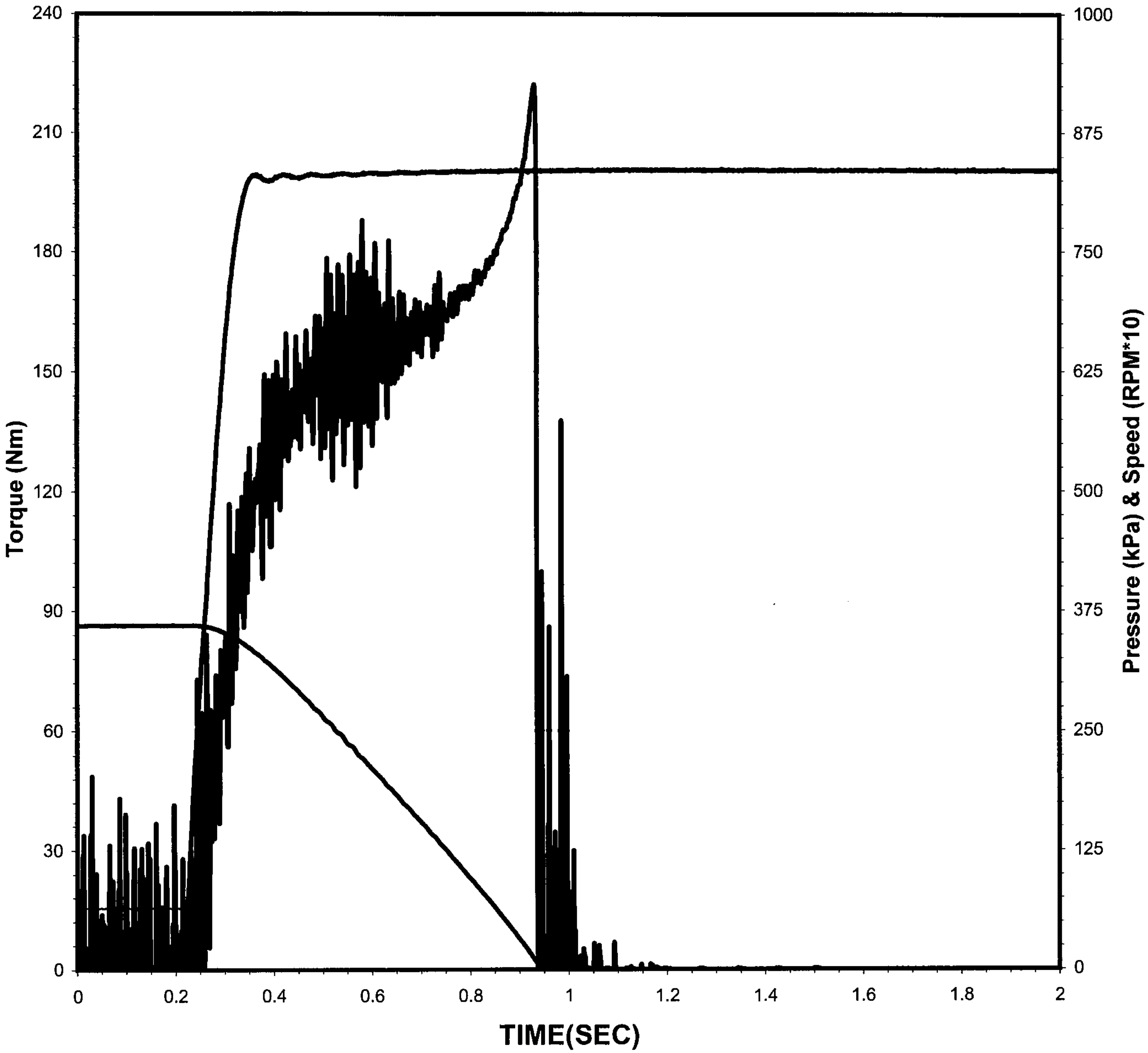
0.2 Sec Dyn:	31 N*m
Midpoint Dyn:	44 N*m
LwSpd Dynamic:	97 N*m

Coefficient of Friction

.2 Sec Dyn:	0.051
Midpoint Dyn:	0.072
LwSpd Dynamic:	0.162

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/20/2010

Time of Test: 16:59:22

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 1010

Temperature: 96.3 °C
(112.7 ± 3.0 °C)

Apply Pressure: 832 kPa
827 ± 7 KPa)

Apply Rate: 0.14 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.716 Sec

Torque

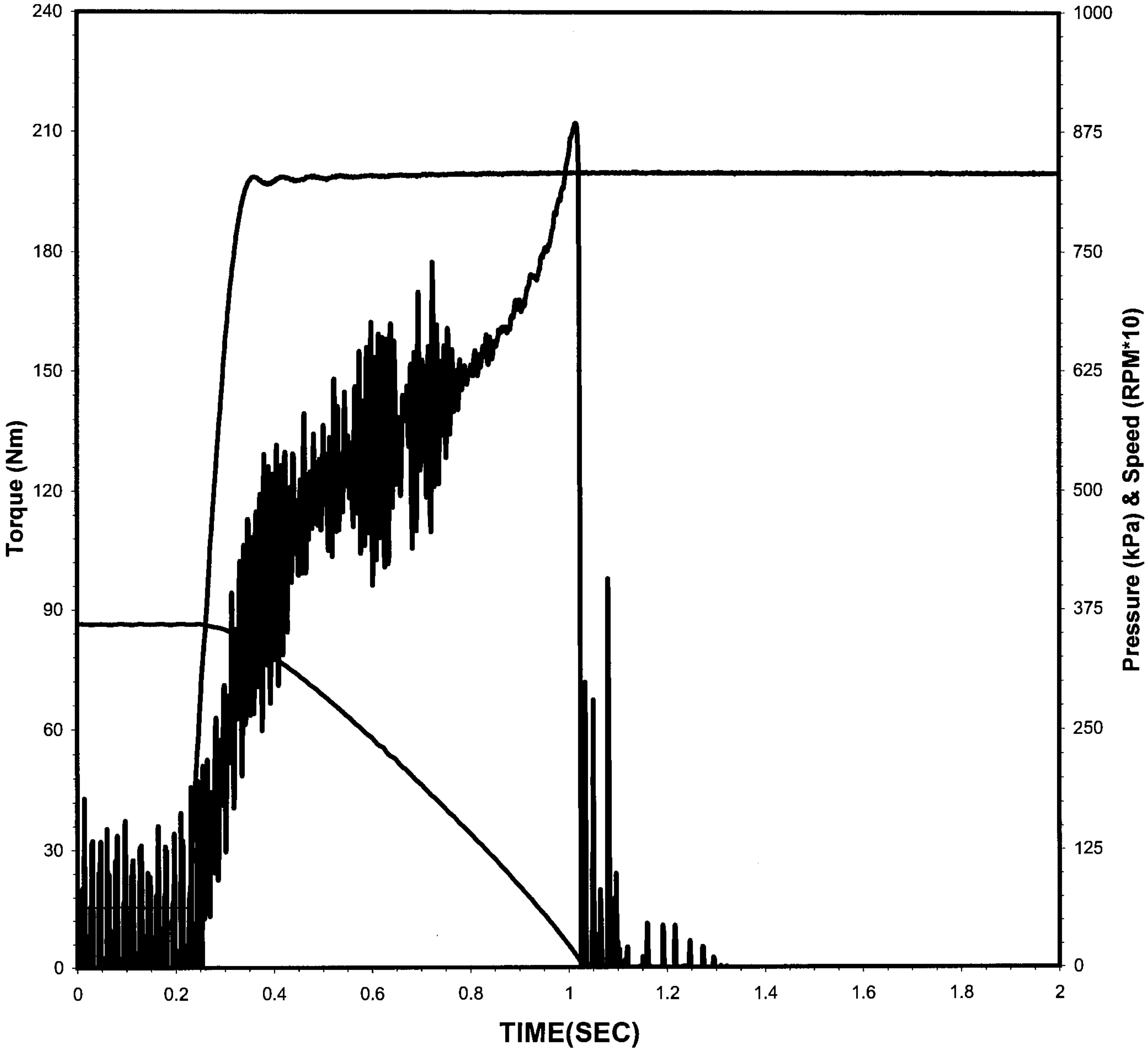
0.2 Sec Dyn:	140 N*m
Midpoint Dyn:	156 N*m
LwSpd Dynamic:	218 N*m

Coefficient of Friction

.2 Sec Dyn:	0.097
Midpoint Dyn:	0.108
LwSpd Dynamic:	0.151

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/20/2010

Time of Test: 19:01:37

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 1499

Temperature: 113.6 °C
(112.7 ± 3.0 °C)

Apply Pressure: 830 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.801 Sec

Torque

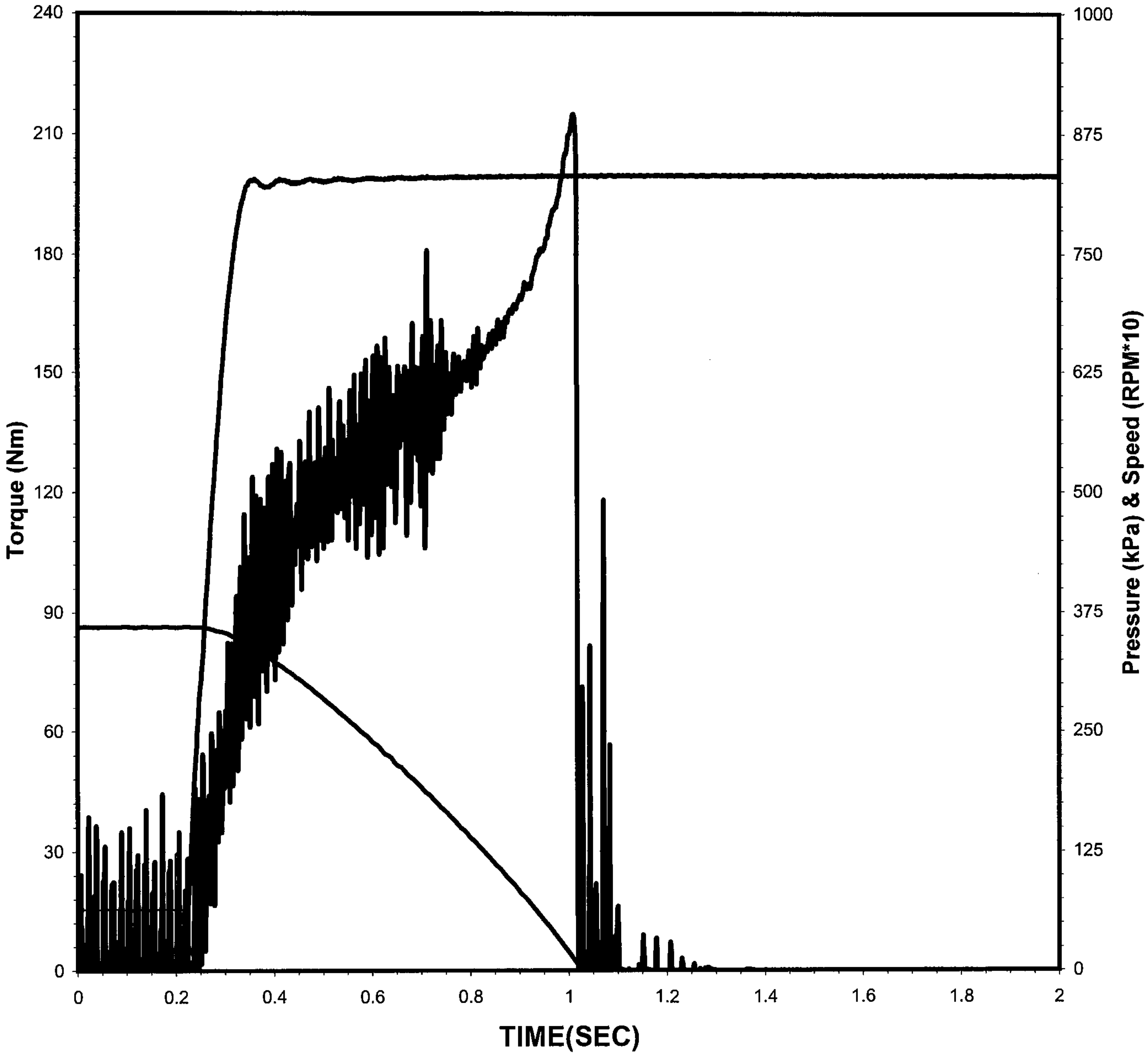
0.2 Sec Dyn:	107 N*m
Midpoint Dyn:	132 N*m
LwSpd Dynamic:	203 N*m

Coefficient of Friction

.2 Sec Dyn:	0.074
Midpoint Dyn:	0.091
LwSpd Dynamic:	0.140

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	19:01:52
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	1500
Temperature:	113.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	830 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.798 Sec

Torque

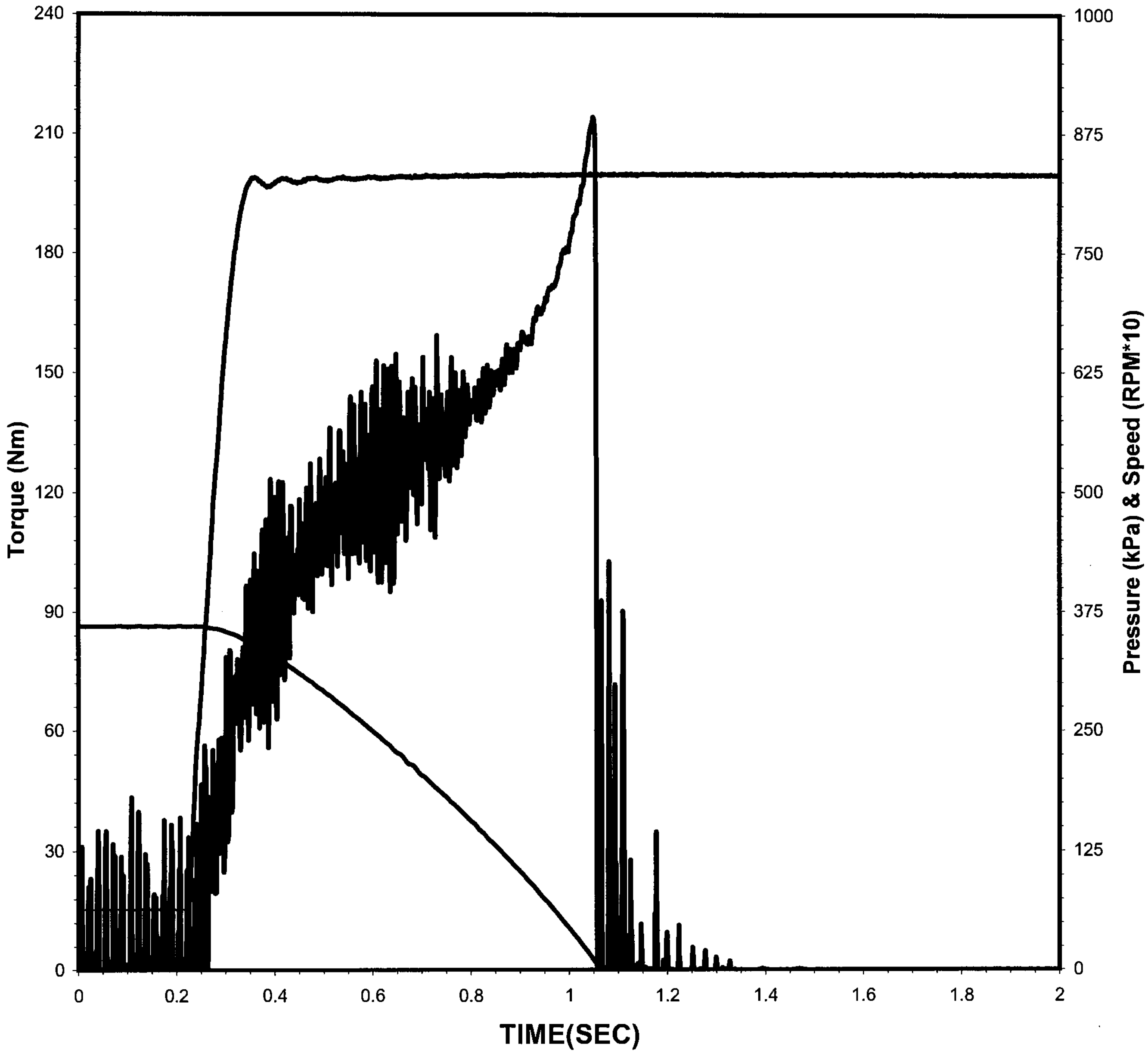
0.2 Sec Dyn:	107 N*m
Midpoint Dyn:	133 N*m
LwSpd Dynamic:	206 N*m

Coefficient of Friction

.2 Sec Dyn:	0.074
Midpoint Dyn:	0.092
LwSpd Dynamic:	0.142

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/20/2010

Time of Test: 19:02:19

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 1501

Temperature: 109.4 °C
(112.7 ± 3.0 °C)

Apply Pressure: 831 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.835 Sec

Torque

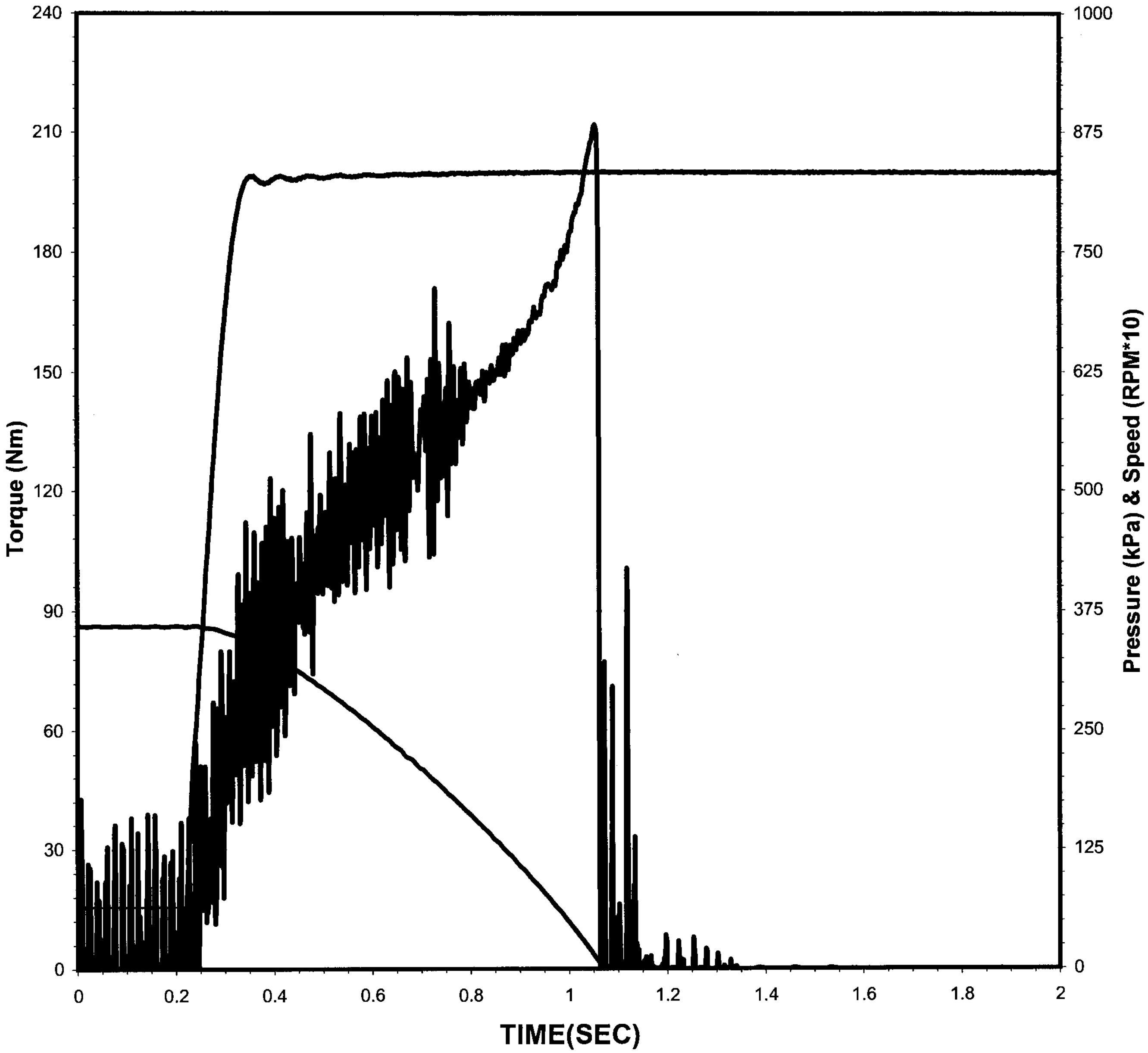
0.2 Sec Dyn:	99 N*m
Midpoint Dyn:	127 N*m
LwSpd Dynamic:	208 N*m

Coefficient of Friction

.2 Sec Dyn:	0.068
Midpoint Dyn:	0.088
LwSpd Dynamic:	0.143

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	21:06:49
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	1999
Temperature:	113.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	831 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.845 Sec

Torque

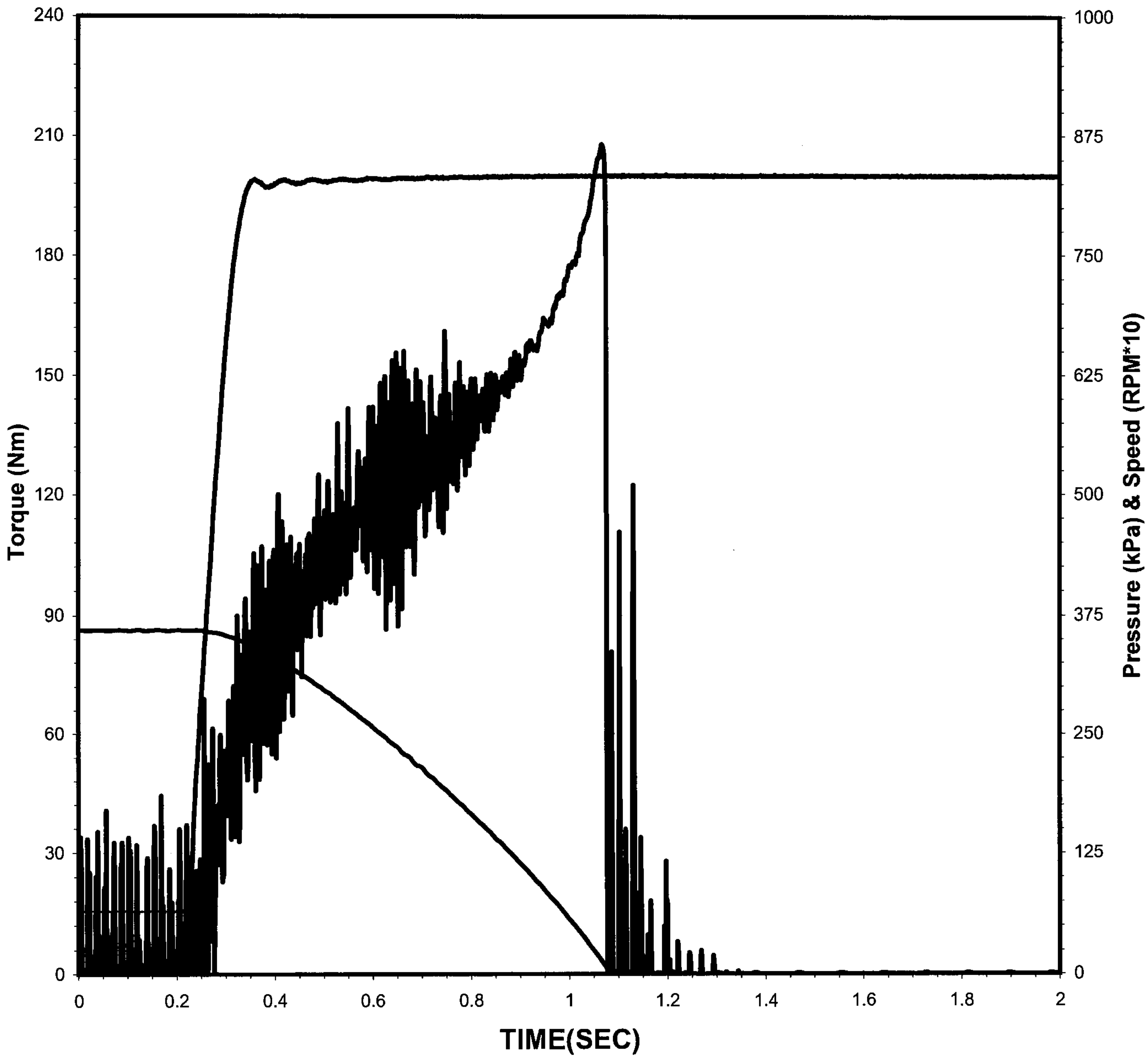
0.2 Sec Dyn:	88 N*m
Midpoint Dyn:	126 N*m
LwSpd Dynamic:	205 N*m

Coefficient of Friction

.2 Sec Dyn:	0.061
Midpoint Dyn:	0.087
LwSpd Dynamic:	0.141

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/20/2010**
Time of Test:	**21:07:04**
Test Number:	**C4-7-1285**
Fluid Code:	**LO251746**
Cycle Number:	**2000**
Temperature:	**113.3 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**831 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.854 Sec**

Torque

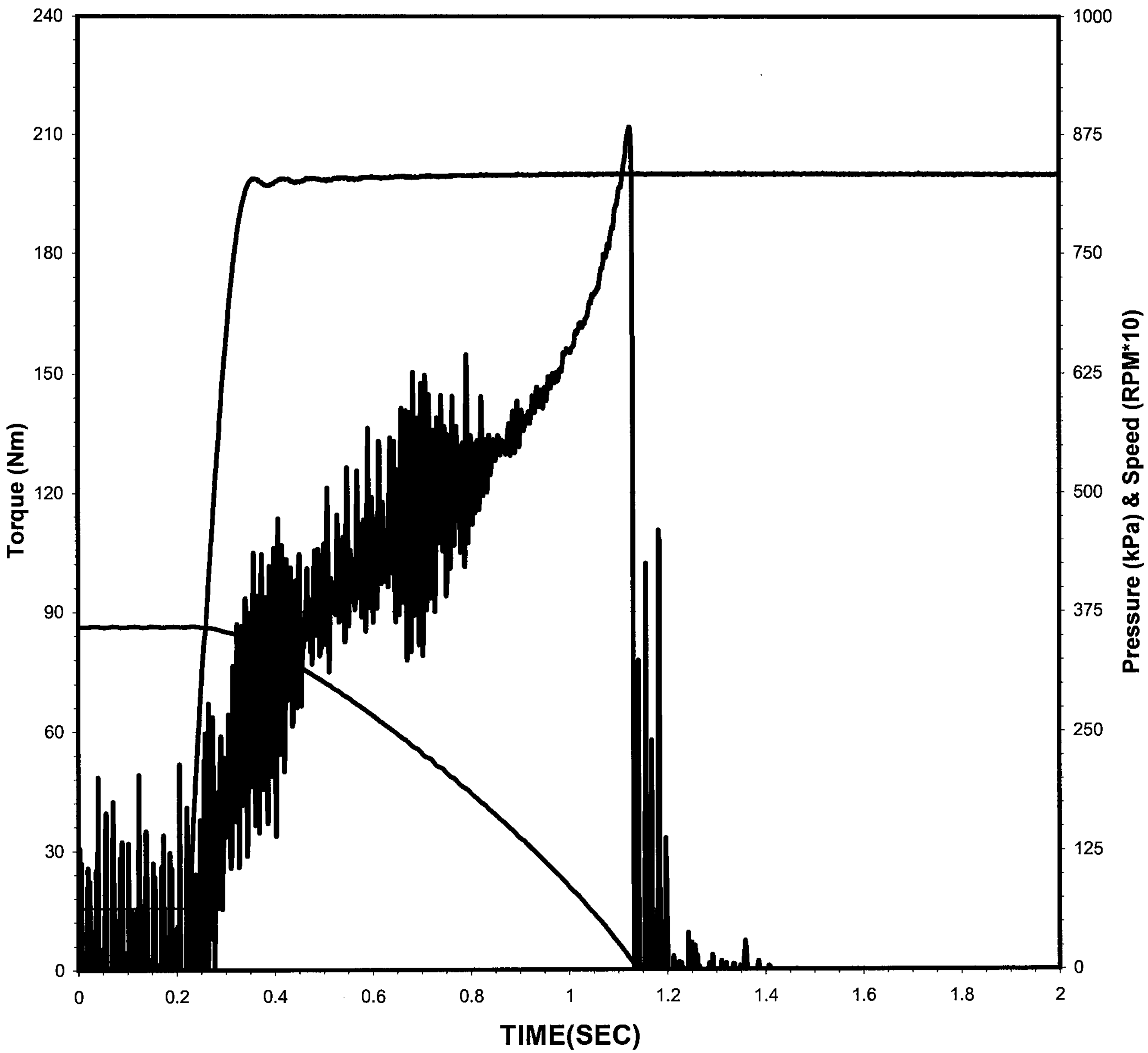
0.2 Sec Dyn:	**89 N*m**
Midpoint Dyn:	**124 N*m**
LwSpd Dynamic:	**201 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.061**
Midpoint Dyn:	**0.086**
LwSpd Dynamic:	**0.139**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/20/2010

Time of Test: 21:07:31

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 2001

Temperature: 108.9 °C
(112.7 ± 3.0 °C)

Apply Pressure: 831 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.909 Sec

Torque

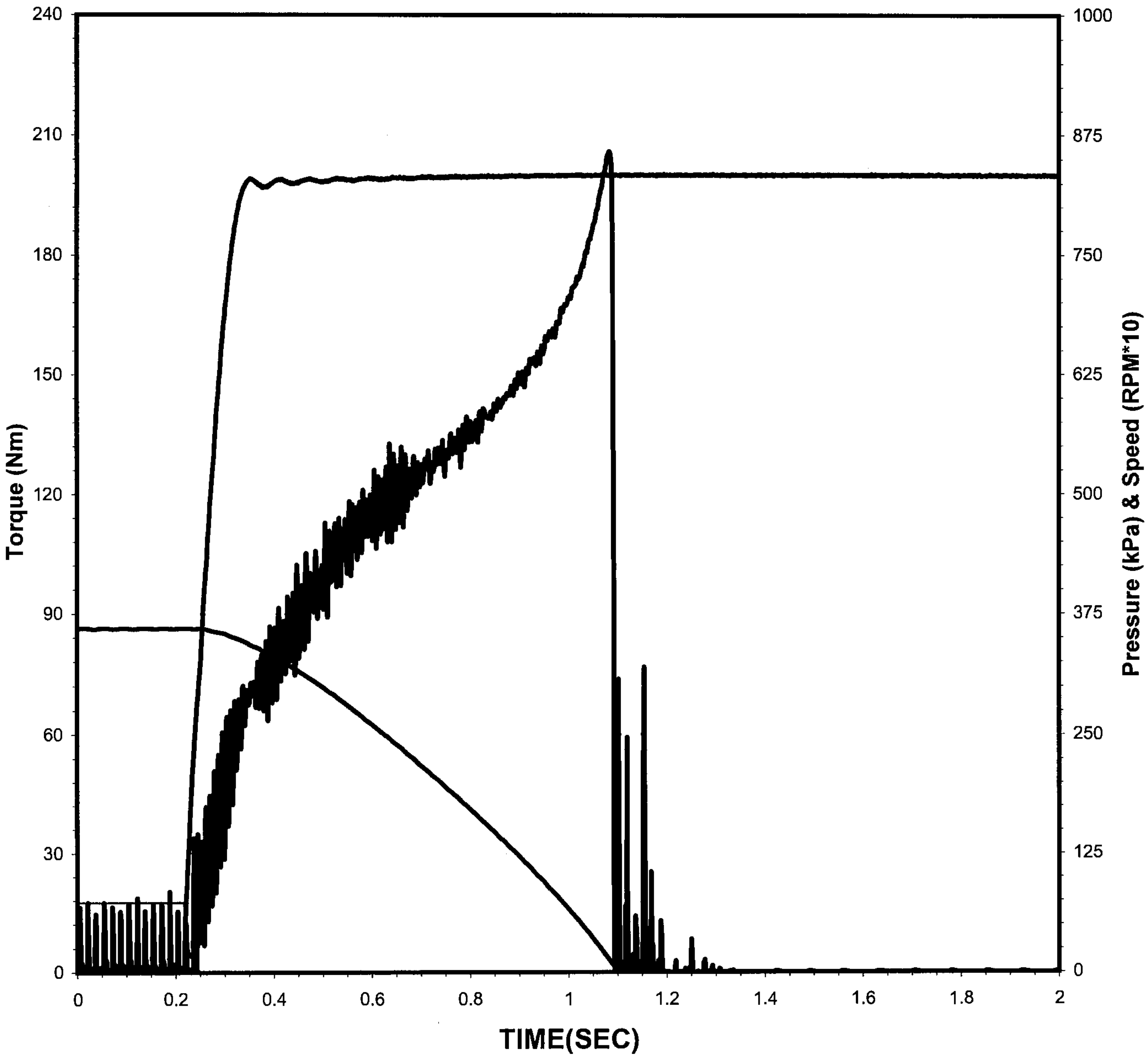
0.2 Sec Dyn:	**81 N*m**
Midpoint Dyn:	**114 N*m**
LwSpd Dynamic:	**206 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.056**
Midpoint Dyn:	**0.079**
LwSpd Dynamic:	**0.142**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/20/2010**
Time of Test:	**23:24:18**
Test Number:	**C4-7-1285**
Fluid Code:	**LO251746**
Cycle Number:	**2499**
Temperature:	**113.4 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**832 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.877 Sec**

Torque

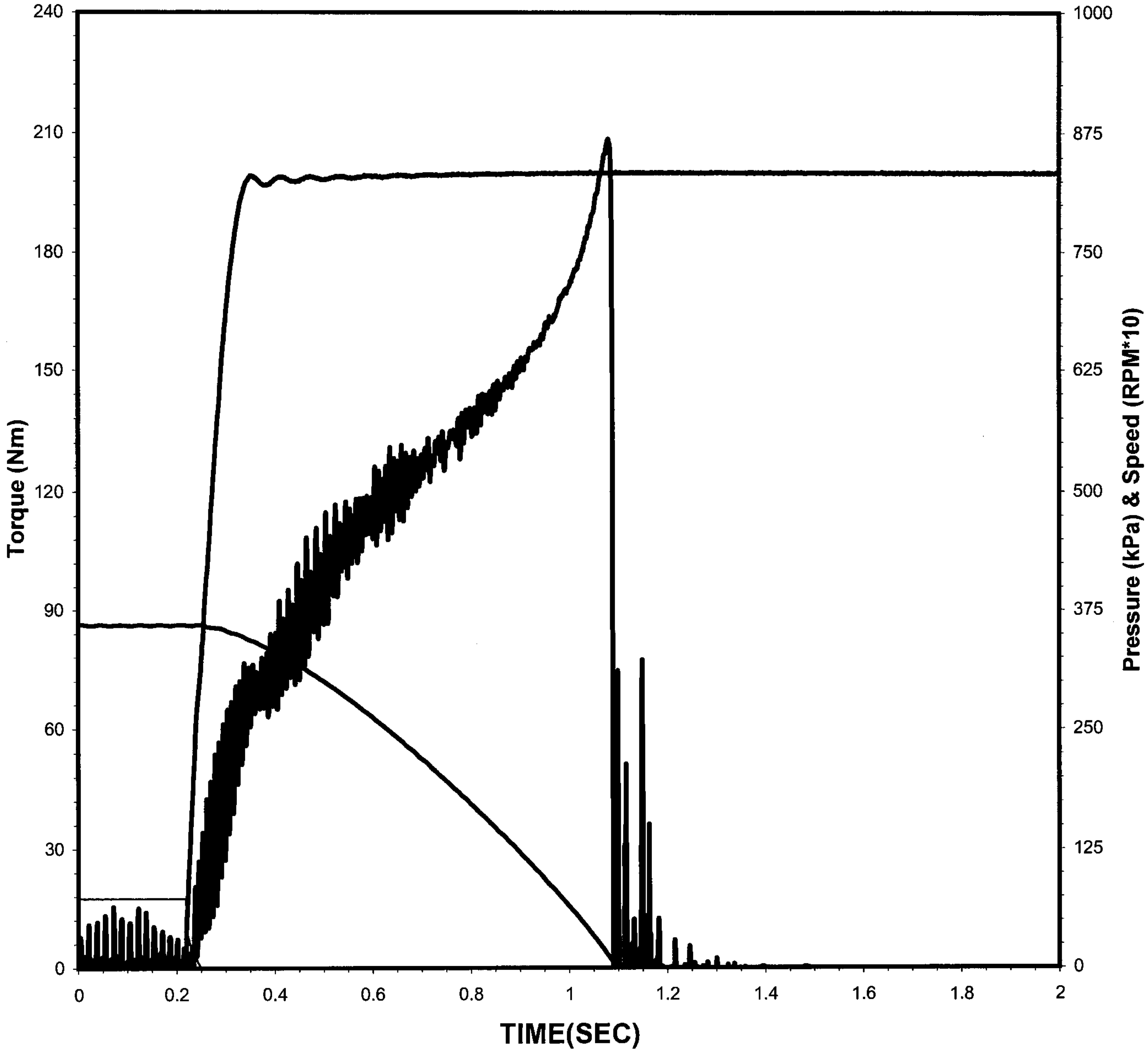
0.2 Sec Dyn:	**82 N*m**
Midpoint Dyn:	**121 N*m**
LwSpd Dynamic:	**201 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.057**
Midpoint Dyn:	**0.084**
LwSpd Dynamic:	**0.139**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/20/2010
Time of Test:	23:24:33
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	2500
Temperature:	113.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.872 Sec

Torque

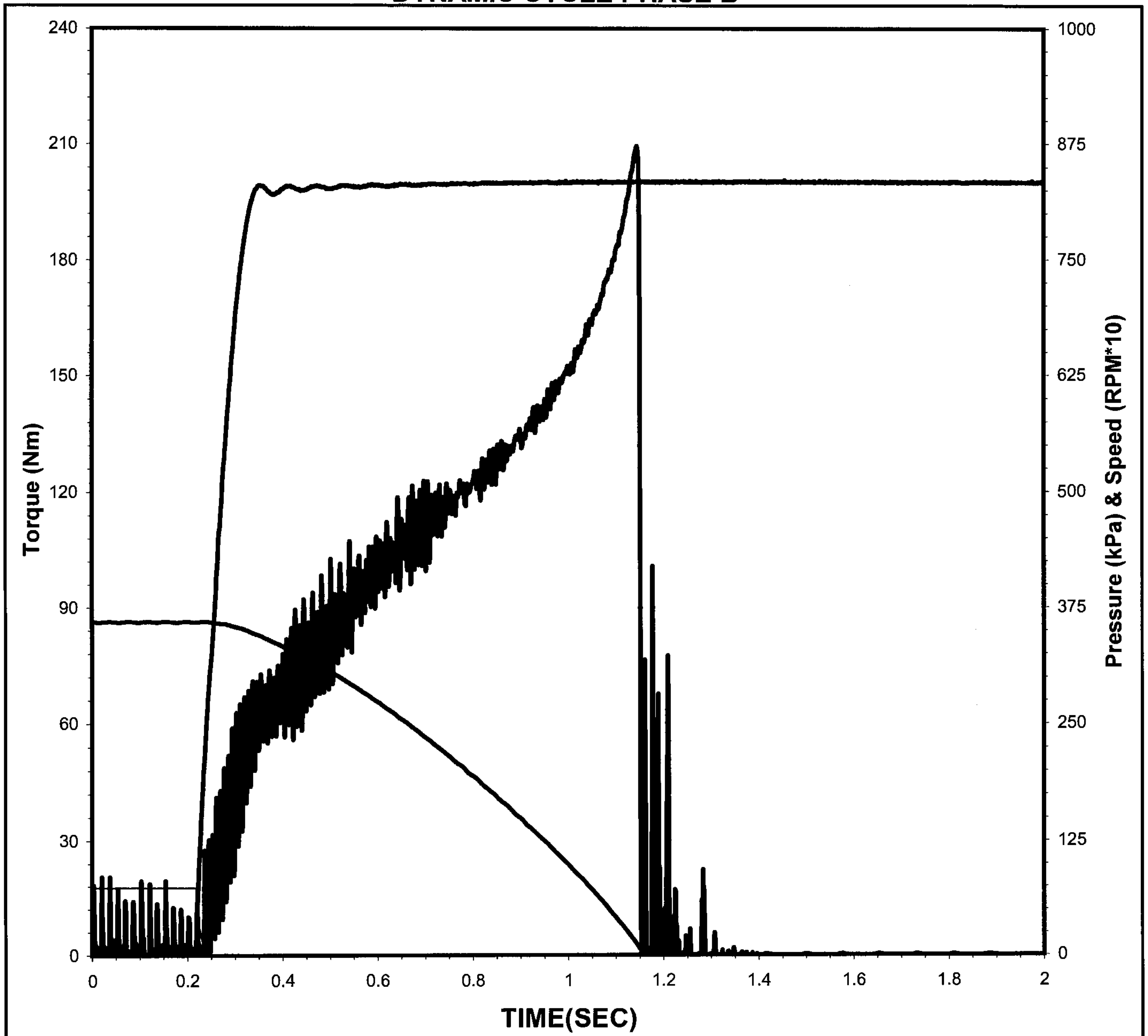
0.2 Sec Dyn:	80 N*m
Midpoint Dyn:	122 N*m
LwSpd Dynamic:	203 N*m

Coefficient of Friction

.2 Sec Dyn:	0.055
Midpoint Dyn:	0.084
LwSpd Dynamic:	0.140

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/20/2010**
Time of Test:	**23:25:00**
Test Number:	**C4-7-1285**
Fluid Code:	**LO251746**
Cycle Number:	**2501**
Temperature:	**109.2 °C**
	(112.7 ± 3.0 °C)
Apply Pressure:	**832 kPa**
	827 ± 7 KPa)
Apply Rate:	**0.13 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.4 KJ**
	(18.71 ± 0.40 KJ)
Engage Time:	**0.935 Sec**

Torque

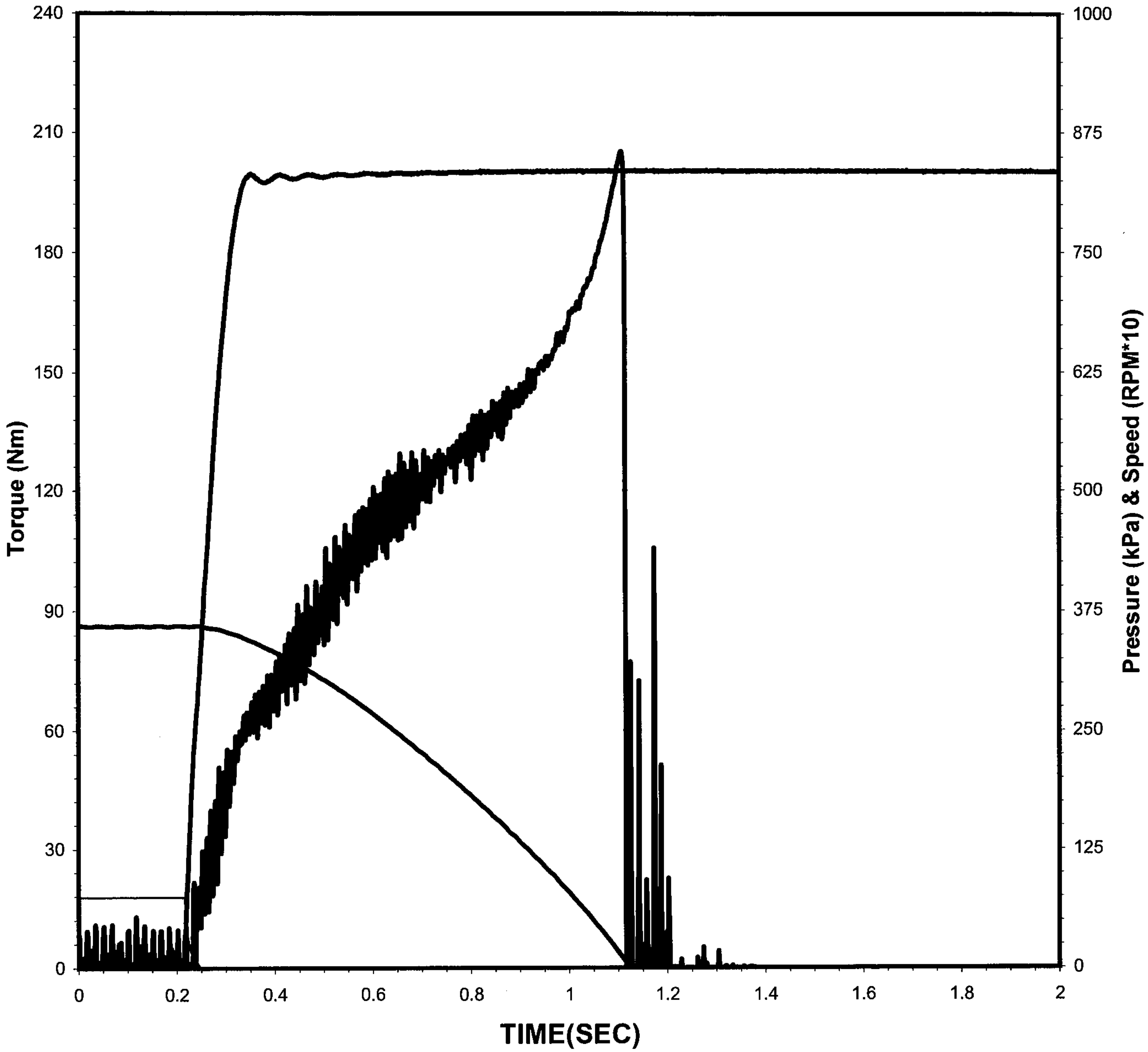
0.2 Sec Dyn:	**73 N*m**
Midpoint Dyn:	**111 N*m**
LwSpd Dynamic:	**202 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.050**
Midpoint Dyn:	**0.077**
LwSpd Dynamic:	**0.139**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	1:29:30
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	2999
Temperature:	113.7 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.9 Sec

Torque

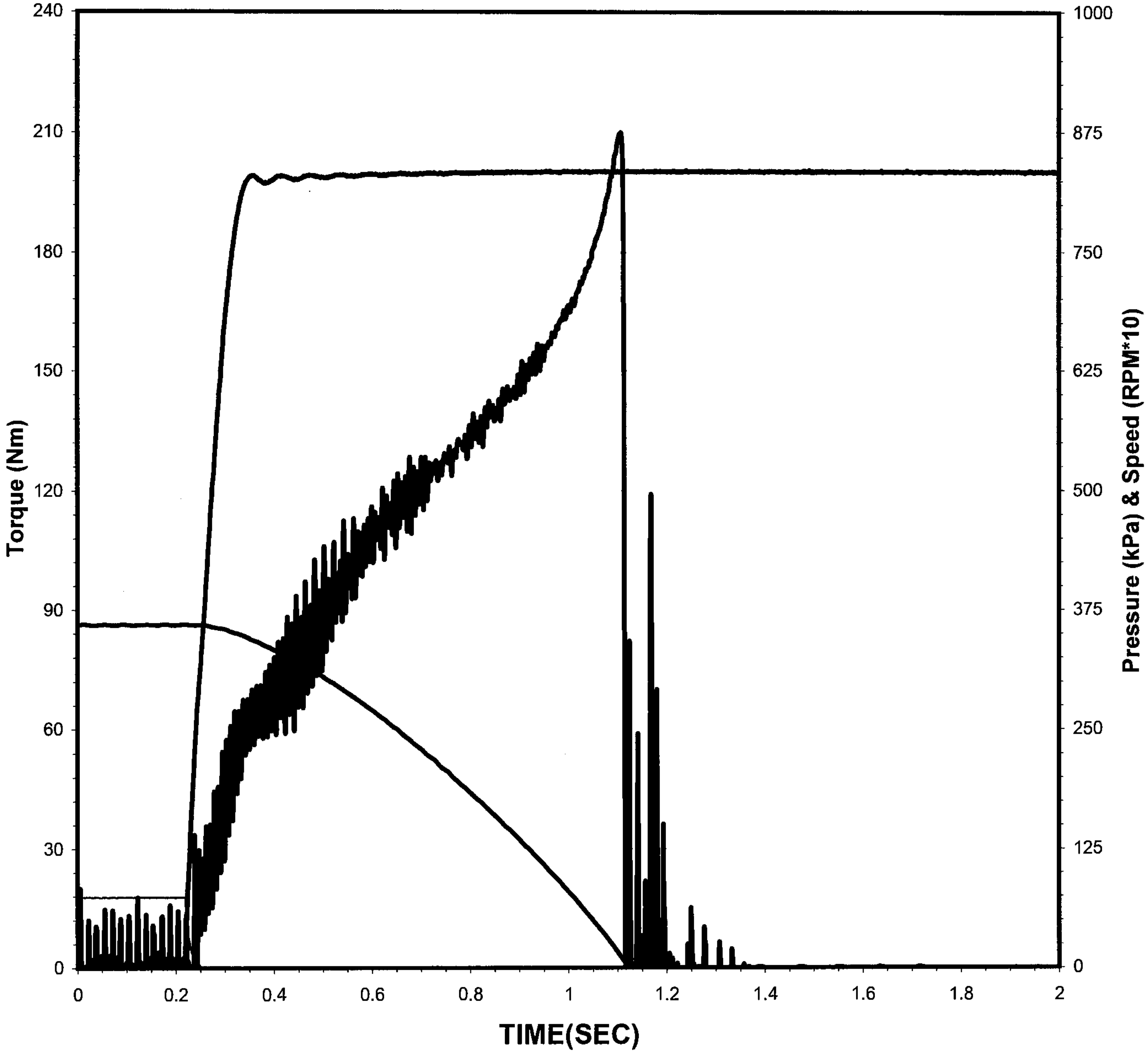
0.2 Sec Dyn:	75 N*m
Midpoint Dyn:	119 N*m
LwSpd Dynamic:	198 N*m

Coefficient of Friction

.2 Sec Dyn:	0.052
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 1:29:45

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 3000

Temperature: 113.6 °C (112.7 ± 3.0 °C)

Apply Pressure: 833 kPa 827 ± 7 KPa)

Apply Rate: 0.13 Sec (0.15 ± 0.02 Sec)

Energy: 18.4 KJ (18.71 ± 0.40 KJ)

Engage Time: 0.896 Sec

Torque

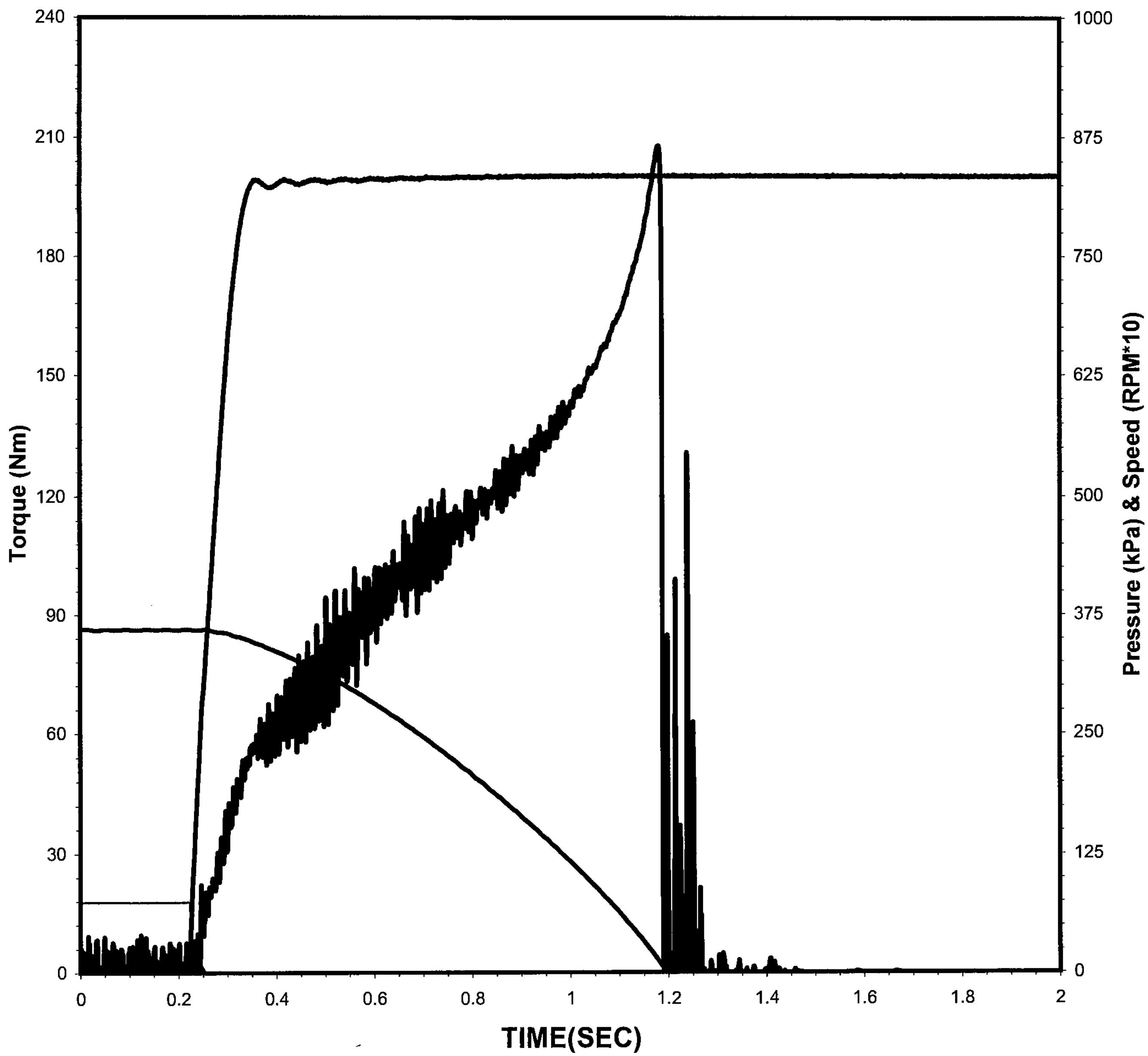
0.2 Sec Dyn:	74 N*m
Midpoint Dyn:	118 N*m
LwSpd Dynamic:	204 N*m

Coefficient of Friction

.2 Sec Dyn:	0.051
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.141

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/21/2010**
Time of Test:	**1:30:12**
Test Number:	**C4-7-1285**
Fluid Code:	**LO251746**
Cycle Number:	**3001**
Temperature:	**109.6 °C** (112.7 ± 3.0 °C)
Apply Pressure:	**833 kPa** 827 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.4 KJ** (18.71 ± 0.40 KJ)
Engage Time:	**0.967 Sec**

Torque

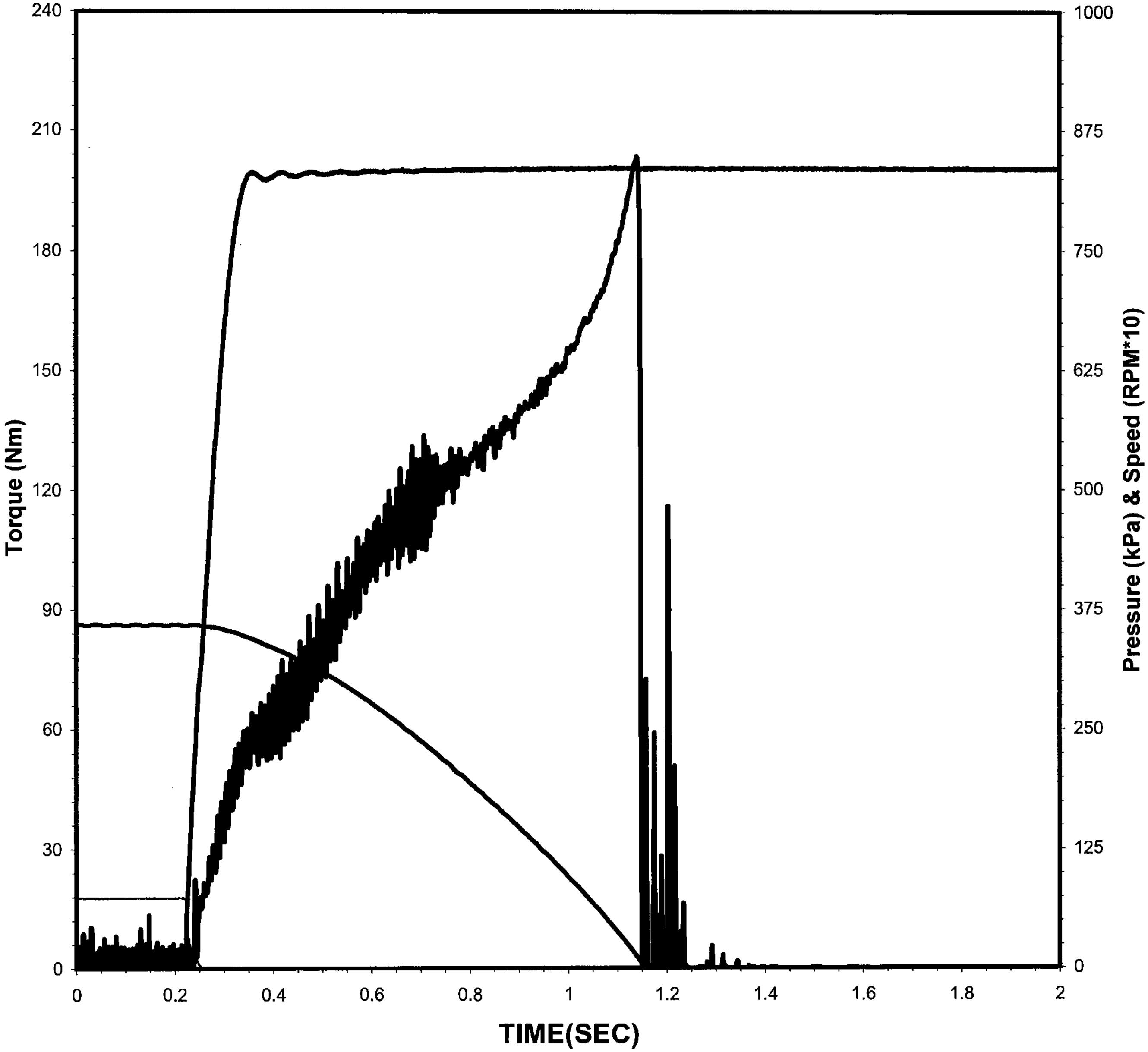
0.2 Sec Dyn:	**66 N*m**
Midpoint Dyn:	**106 N*m**
LwSpd Dynamic:	**199 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.046**
Midpoint Dyn:	**0.073**
LwSpd Dynamic:	**0.138**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 3:34:42

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 3499

Temperature: 113.5 °C
(112.7 ± 3.0 °C)

Apply Pressure: 833 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.3 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.927 Sec

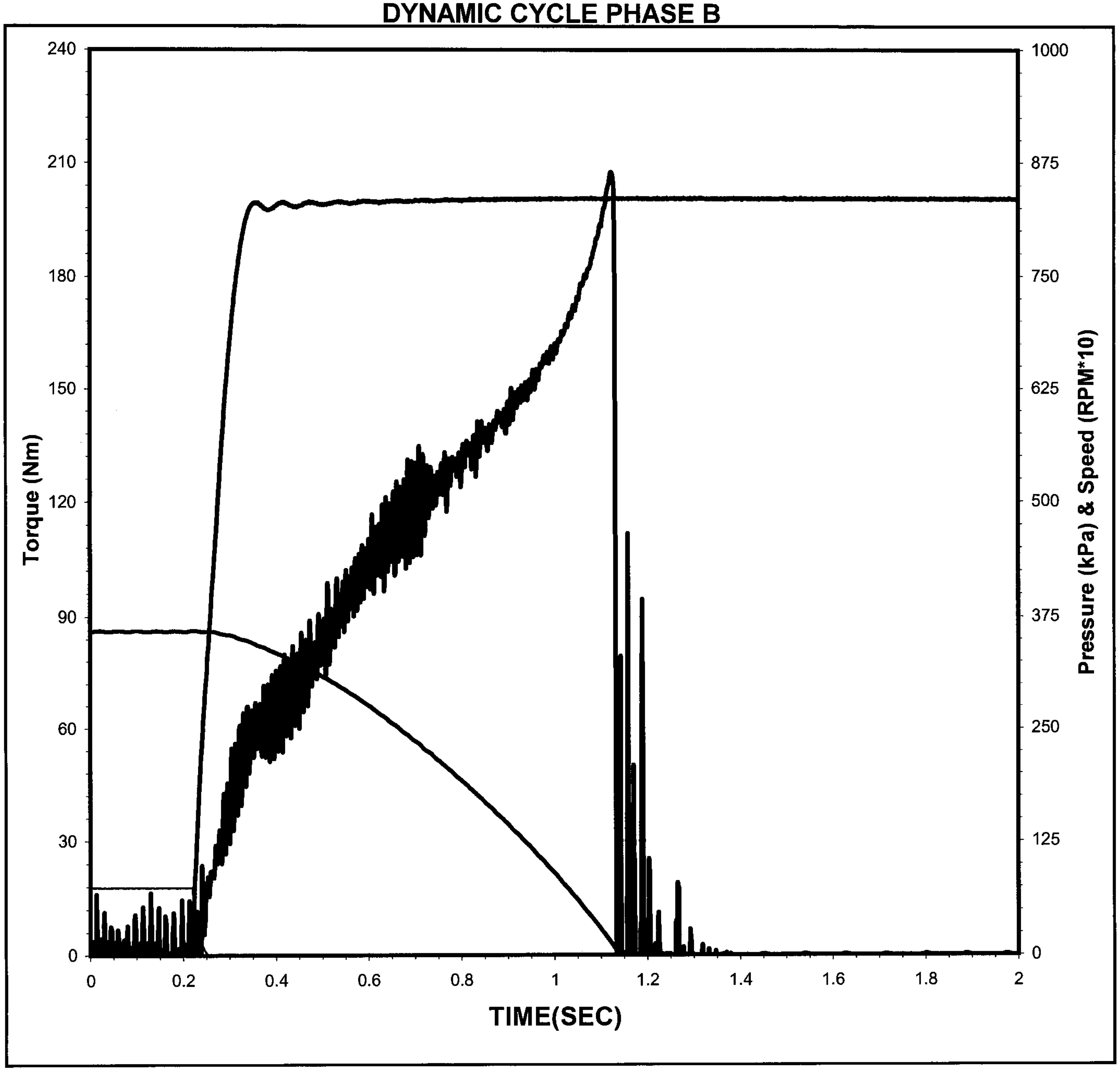
Torque

0.2 Sec Dyn:	67 N*m
Midpoint Dyn:	116 N*m
LwSpd Dynamic:	195 N*m

Coefficient of Friction

.2 Sec Dyn:	0.046
Midpoint Dyn:	0.080
LwSpd Dynamic:	0.135

ALLISON C-4 GRAPHITE DATA



Date of Test: 7/21/2010

Time of Test: 3:34:57

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 3500

Temperature: 113.7 °C
(112.7 ± 3.0 °C)

Apply Pressure: 833 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.3 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.913 Sec

Torque

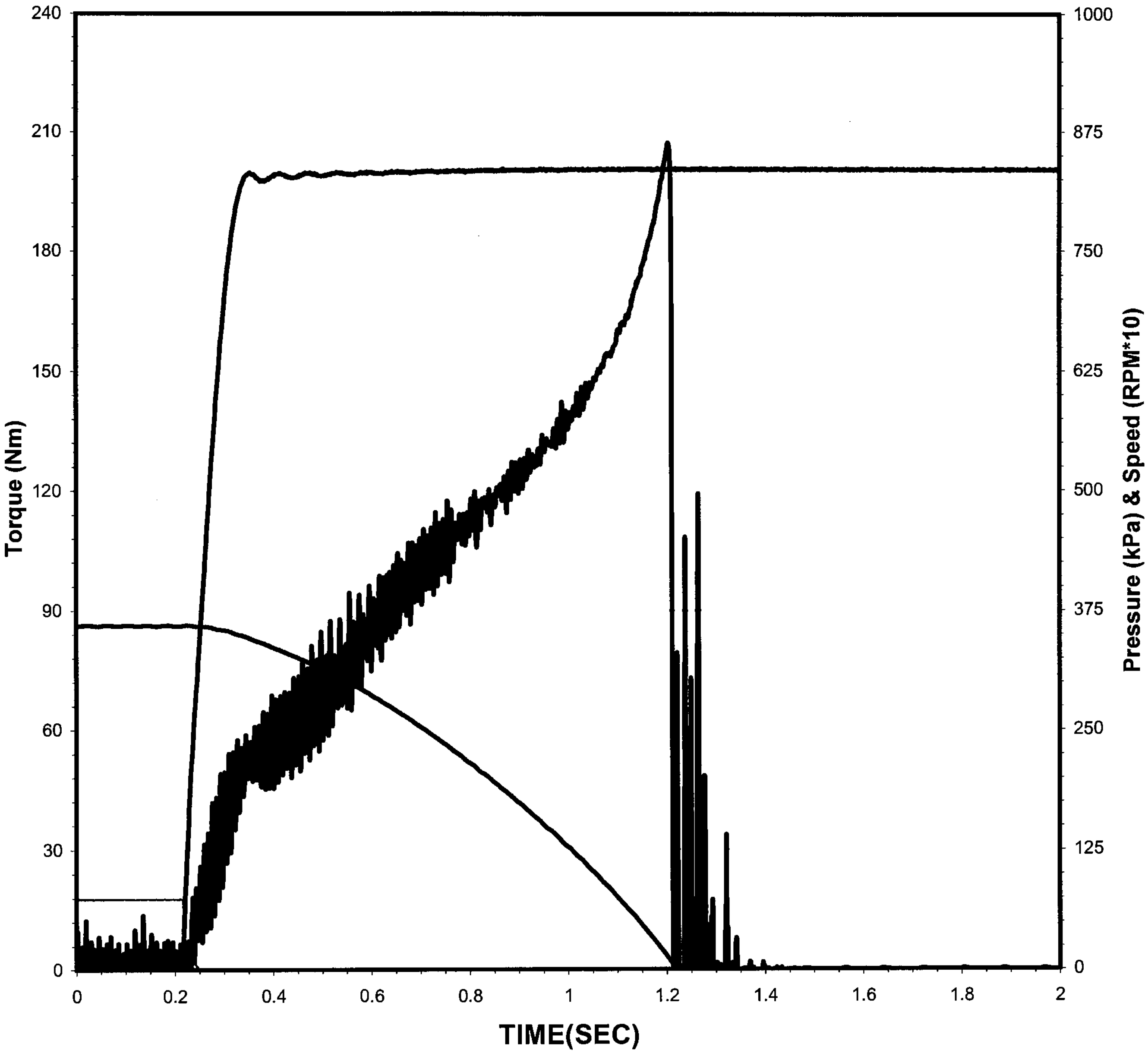
0.2 Sec Dyn:	69 N*m
Midpoint Dyn:	116 N*m
LwSpd Dynamic:	203 N*m

Coefficient of Friction

.2 Sec Dyn:	0.047
Midpoint Dyn:	0.080
LwSpd Dynamic:	0.140

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 3:35:23

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 3501

Temperature: 110.0 °C
(112.7 ± 3.0 °C)

Apply Pressure: 833 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.997 Sec

Torque

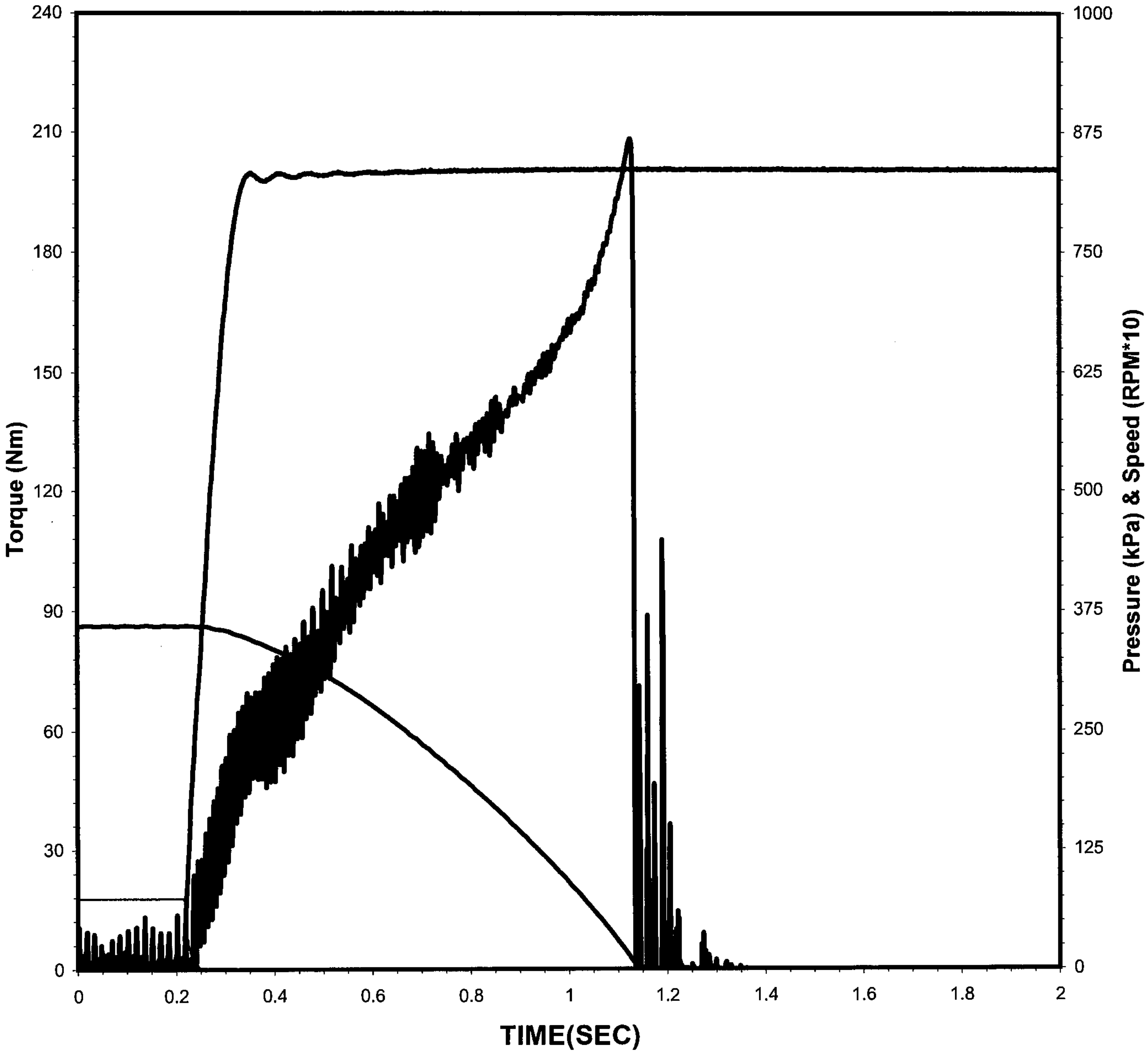
0.2 Sec Dyn:	**60 N*m**
Midpoint Dyn:	**103 N*m**
LwSpd Dynamic:	**199 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.041**
Midpoint Dyn:	**0.071**
LwSpd Dynamic:	**0.137**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	5:39:54
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	3999
Temperature:	113.8 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.918 Sec

Torque

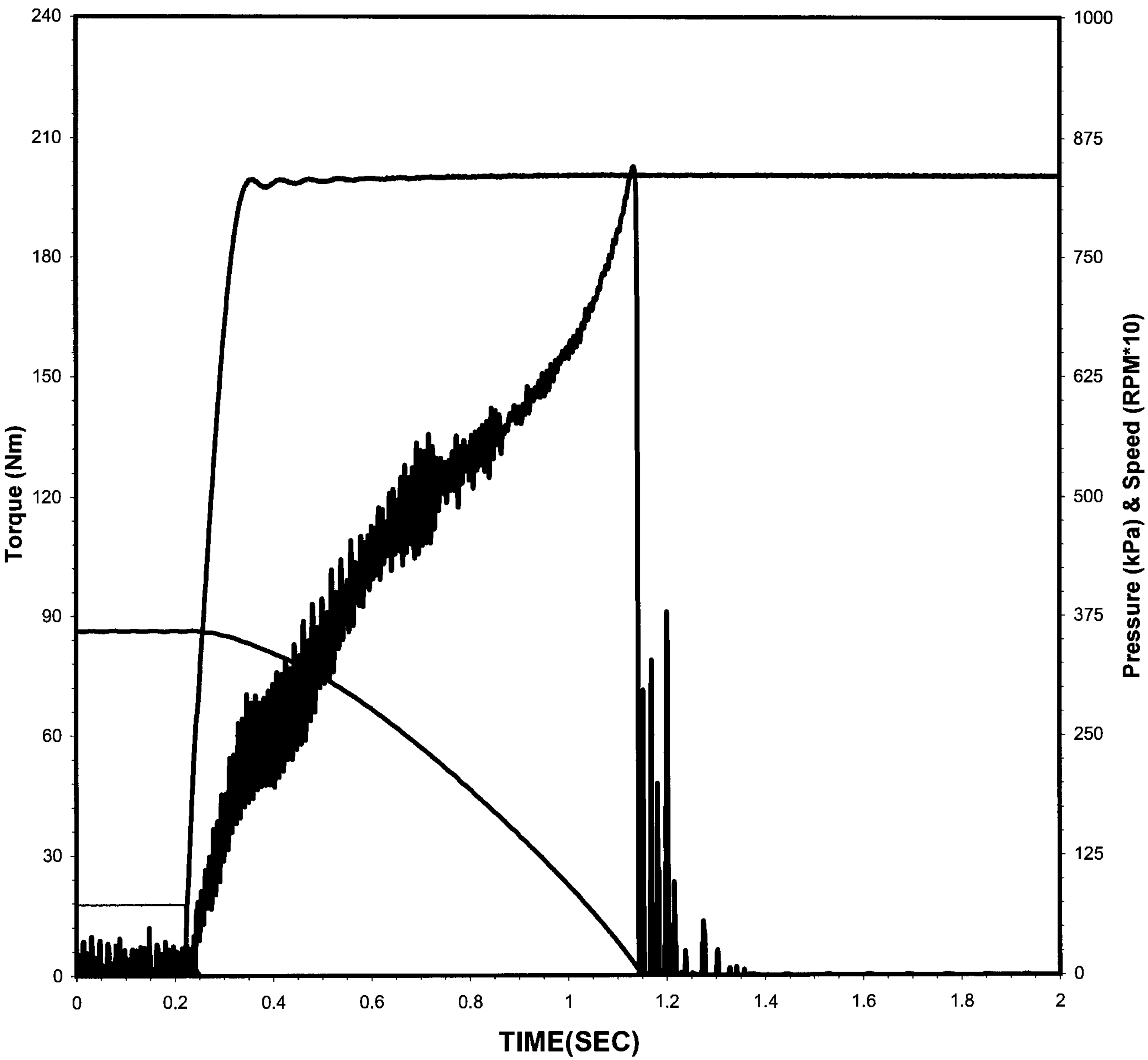
0.2 Sec Dyn:	67 N*m
Midpoint Dyn:	116 N*m
LwSpd Dynamic:	200 N*m

Coefficient of Friction

.2 Sec Dyn:	0.046
Midpoint Dyn:	0.080
LwSpd Dynamic:	0.138

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	**7/21/2010**
Time of Test:	**5:40:09**
Test Number:	**C4-7-1285**
Fluid Code:	**LO251746**
Cycle Number:	**4000**
Temperature:	**113.7 °C**
	(112.7 ± 3.0 °C)
Apply Pressure:	**833 kPa**
	827 ± 7 KPa)
Apply Rate:	**0.13 Sec**
	(0.15 ± 0.02 Sec)
Energy:	**18.3 KJ**
	(18.71 ± 0.40 KJ)
Engage Time:	**0.923 Sec**

Torque

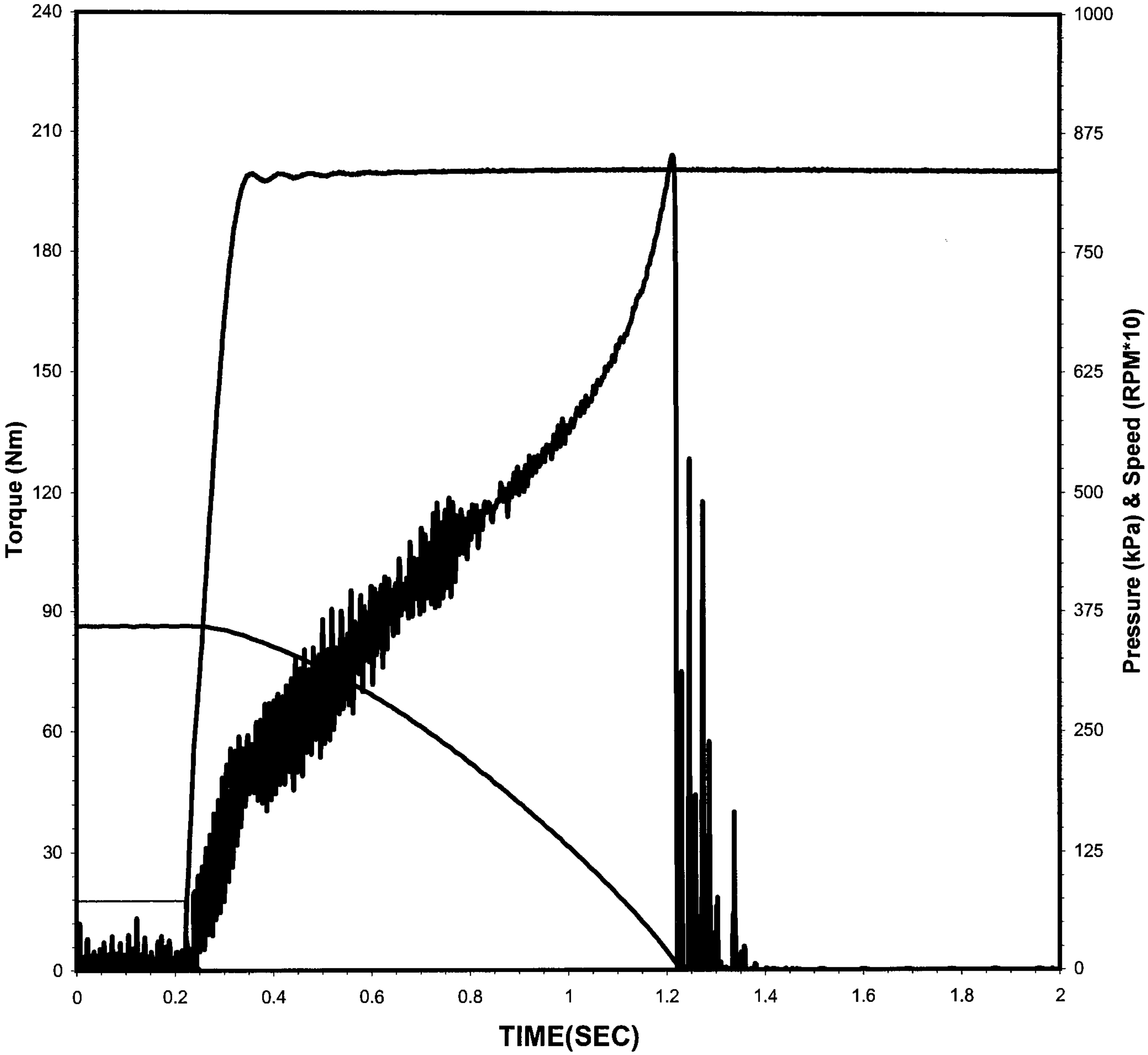
0.2 Sec Dyn:	**66 N*m**
Midpoint Dyn:	**118 N*m**
LwSpd Dynamic:	**196 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.046**
Midpoint Dyn:	**0.081**
LwSpd Dynamic:	**0.135**

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	5:40:35
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	4001
Temperature:	110.0 °C (112.7 ± 3.0 °C)
Apply Pressure:	834 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	1.001 Sec

Torque

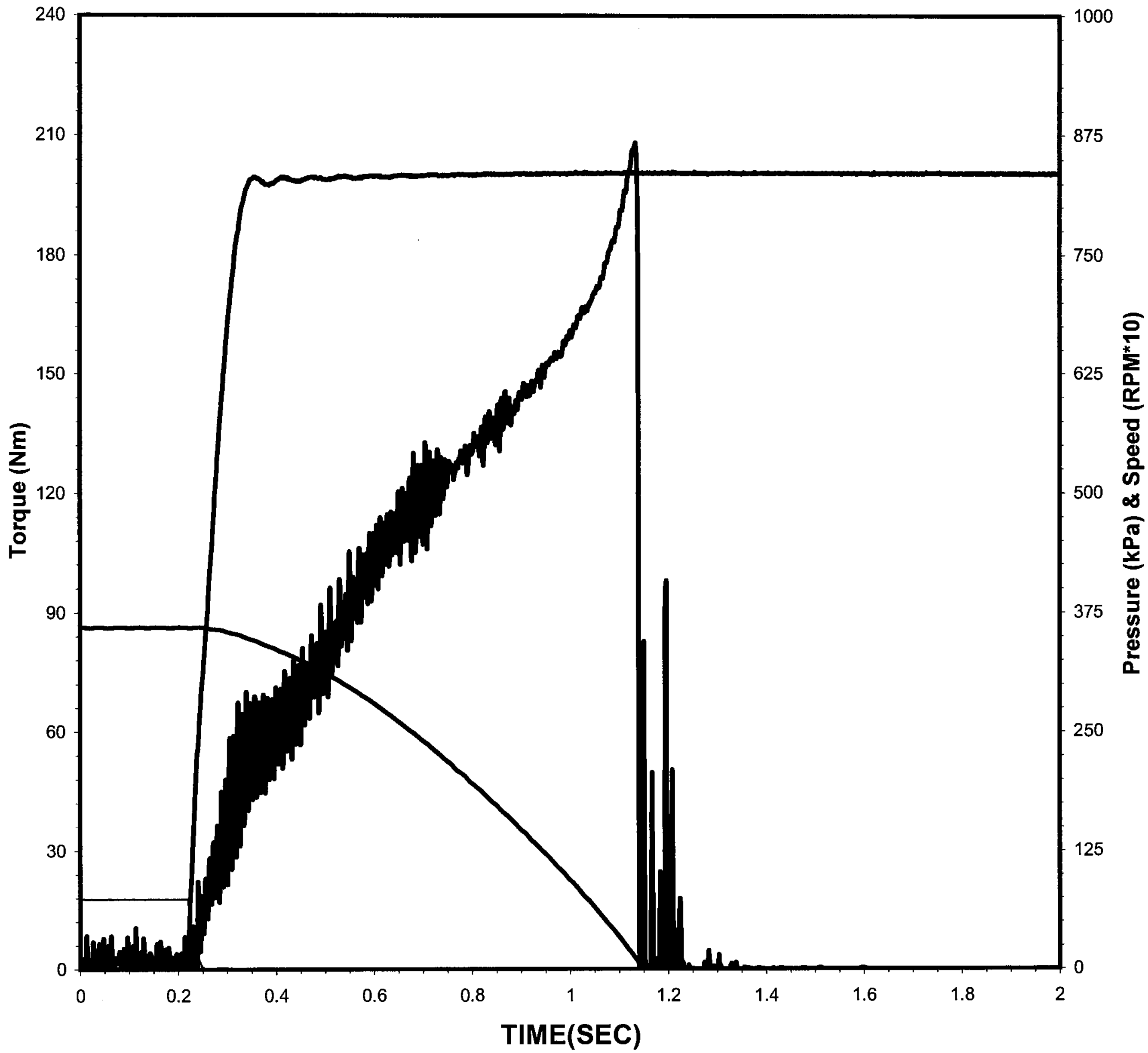
0.2 Sec Dyn:	60 N*m
Midpoint Dyn:	102 N*m
LwSpd Dynamic:	200 N*m

Coefficient of Friction

.2 Sec Dyn:	0.042
Midpoint Dyn:	0.070
LwSpd Dynamic:	0.138

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 7:45:05

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 4499

Temperature: 113.7 °C
(112.7 ± 3.0 °C)

Apply Pressure: 833 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.921 Sec

Torque

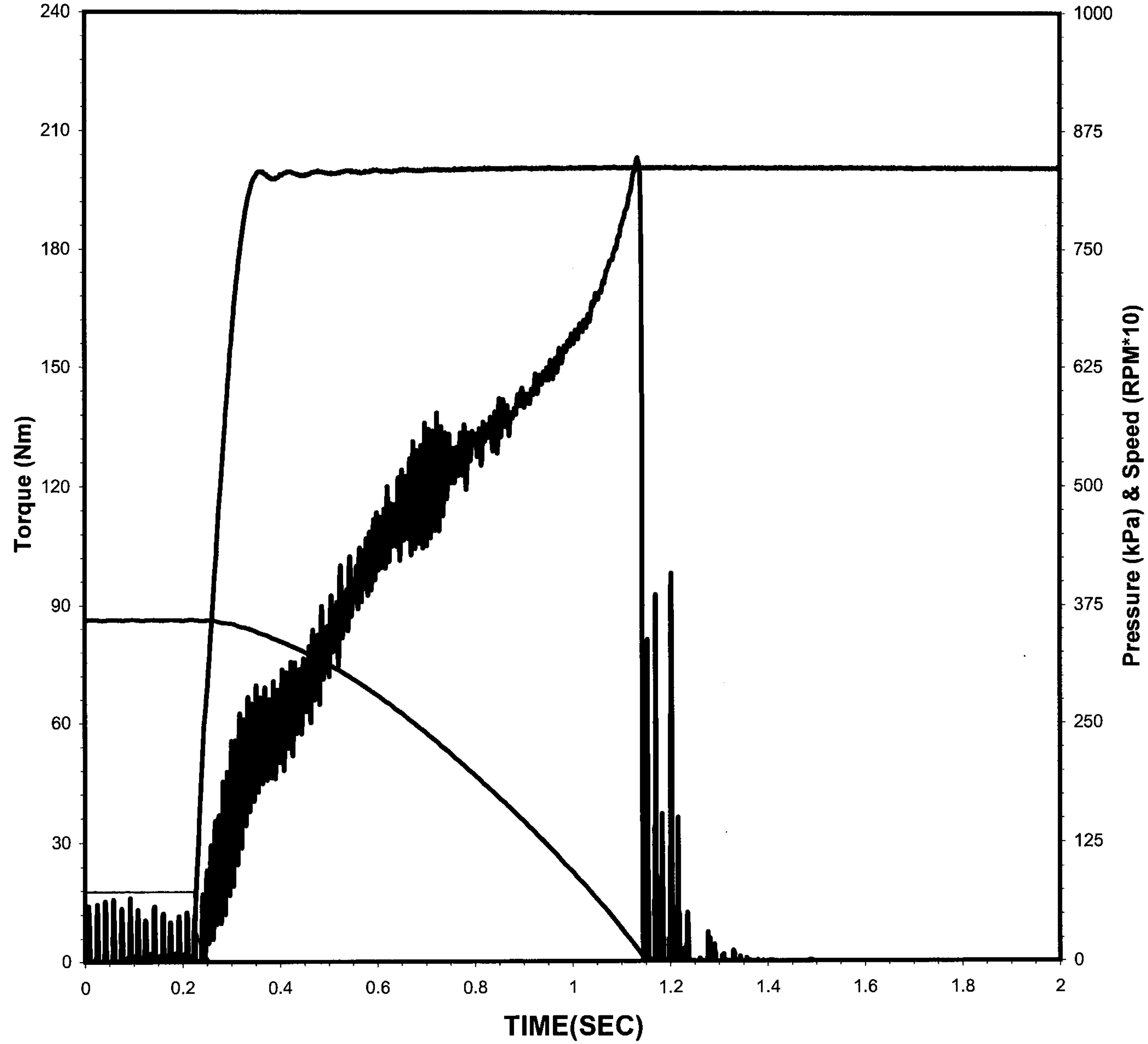
0.2 Sec Dyn:	65 N*m
Midpoint Dyn:	116 N*m
LwSpd Dynamic:	202 N*m

Coefficient of Friction

.2 Sec Dyn:	0.045
Midpoint Dyn:	0.080
LwSpd Dynamic:	0.140

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 7:45:20

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 4500

Temperature: 113.4 °C
(112.7 ± 3.0 °C)

Apply Pressure: 833 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.3 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.921 Sec

Torque

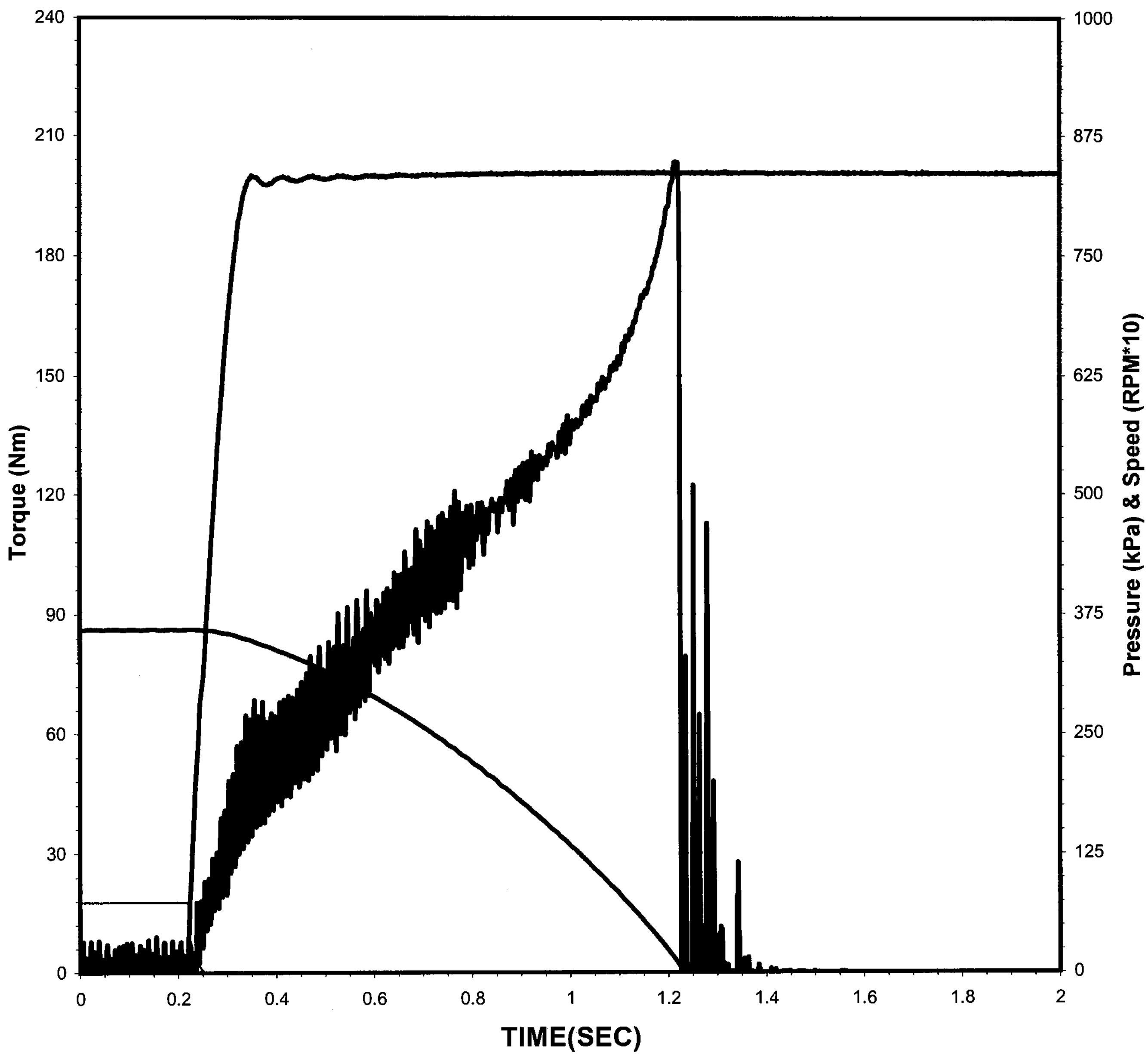
0.2 Sec Dyn:	65 N*m
Midpoint Dyn:	118 N*m
LwSpd Dynamic:	197 N*m

Coefficient of Friction

.2 Sec Dyn:	0.045
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.136

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 7:45:47

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 4501

Temperature: 110.1 °C
(112.7 ± 3.0 °C)
Apply Pressure: 834 kPa
827 ± 7 KPa)
Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)
Energy: 18.4 KJ
(18.71 ± 0.40 KJ)
Engage Time: 1.006 Sec

Torque

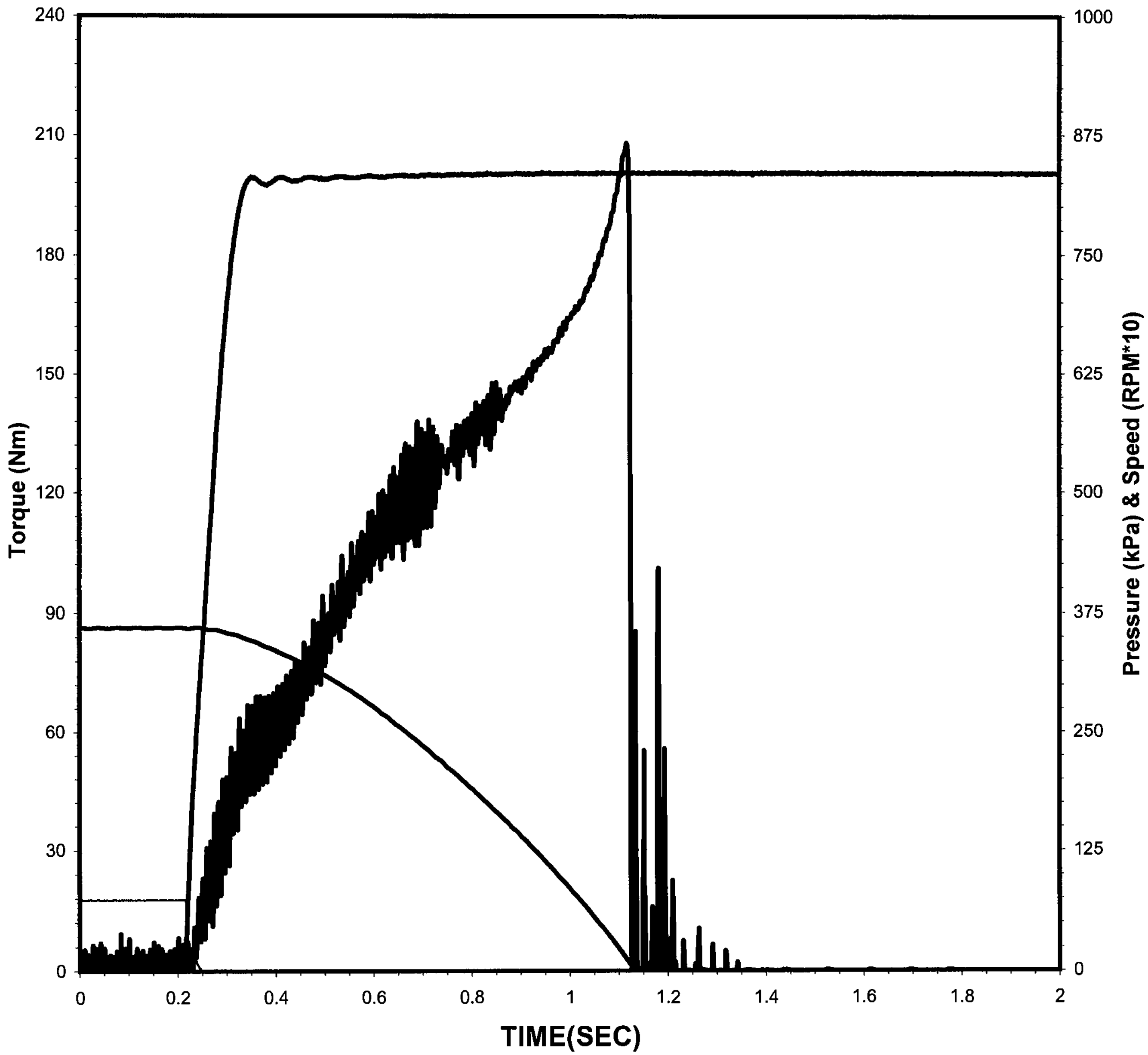
0.2 Sec Dyn: 58 N*m
Midpoint Dyn: 101 N*m
LwSpd Dynamic: 200 N*m

Coefficient of Friction

.2 Sec Dyn: 0.040
Midpoint Dyn: 0.070
LwSpd Dynamic: 0.138

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	9:50:17
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	4999
Temperature:	113.8 °C
	(112.7 ± 3.0 °C)
Apply Pressure:	833 kPa
	827 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.4 KJ
	(18.71 ± 0.40 KJ)
Engage Time:	0.908 Sec

Torque

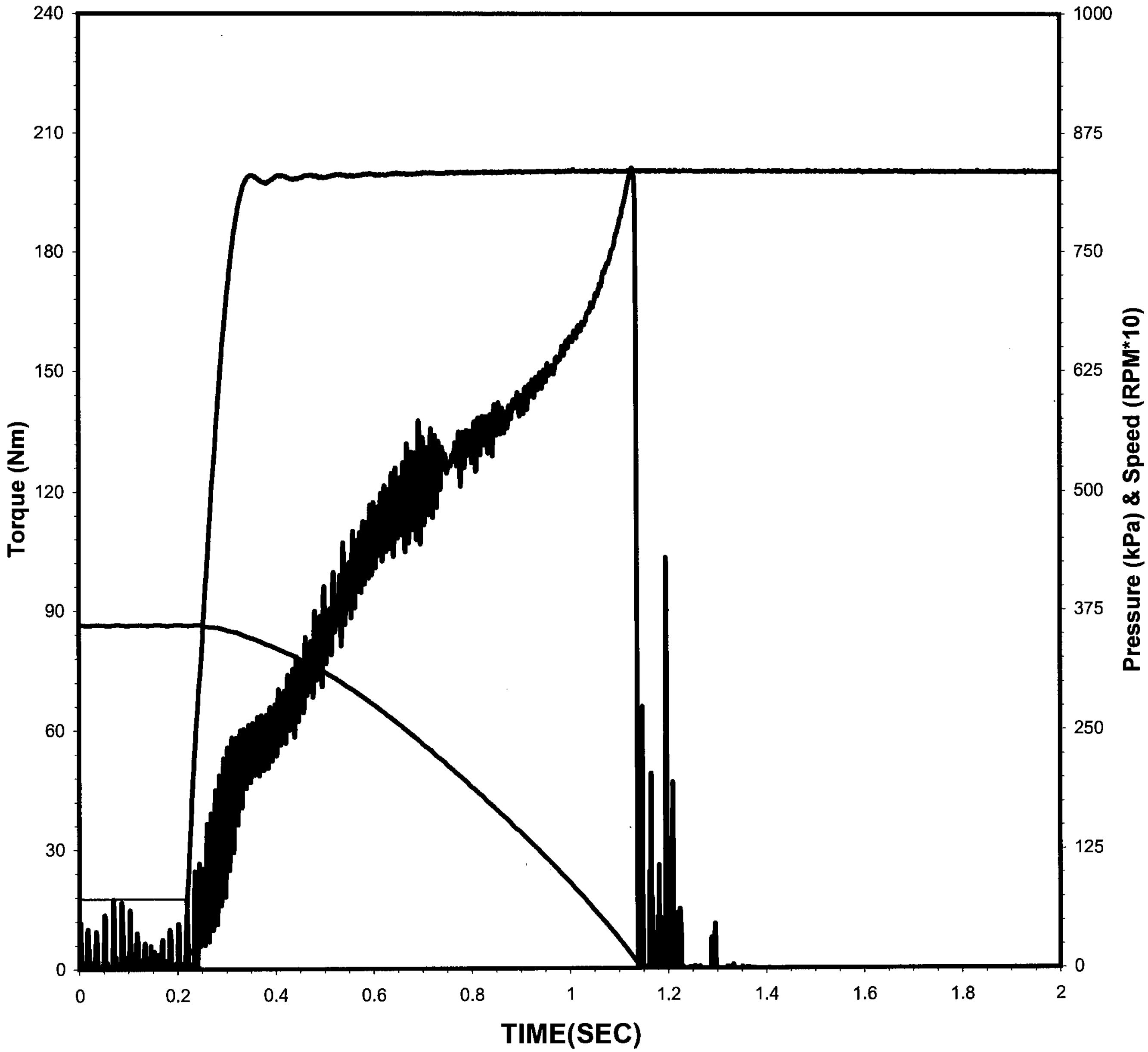
0.2 Sec Dyn:	66 N*m
Midpoint Dyn:	119 N*m
LwSpd Dynamic:	197 N*m

Coefficient of Friction

.2 Sec Dyn:	0.046
Midpoint Dyn:	0.082
LwSpd Dynamic:	0.136

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	9:50:32
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	5000
Temperature:	113.4 °C (112.7 ± 3.0 °C)
Apply Pressure:	833 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.922 Sec

Torque

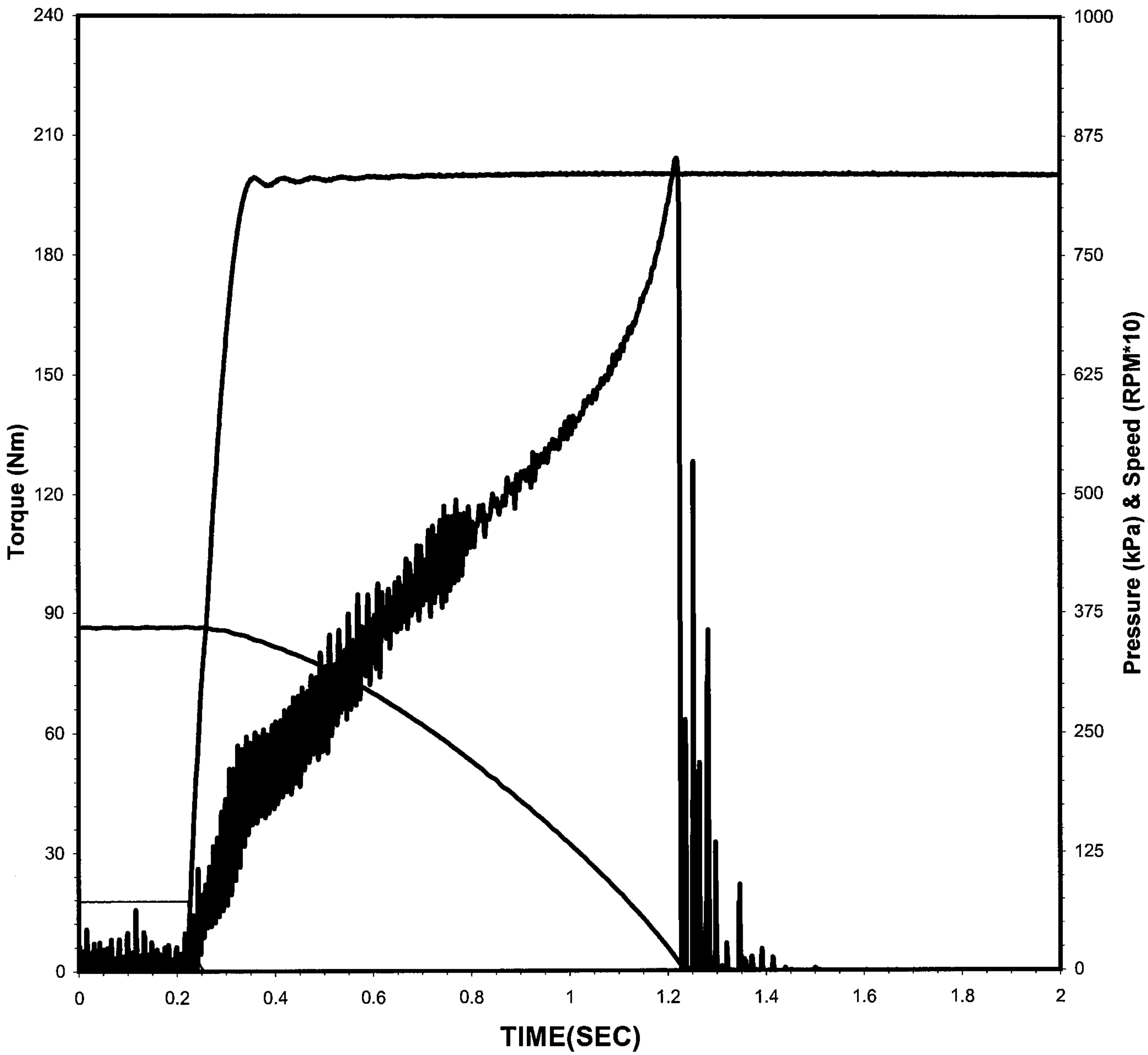
0.2 Sec Dyn:	64 N*m
Midpoint Dyn:	120 N*m
LwSpd Dynamic:	194 N*m

Coefficient of Friction

.2 Sec Dyn:	0.044
Midpoint Dyn:	0.083
LwSpd Dynamic:	0.134

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 9:50:59

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 5001

Temperature: 109.7 °C
(112.7 ± 3.0 °C)

Apply Pressure: 834 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 1.005 Sec

Torque

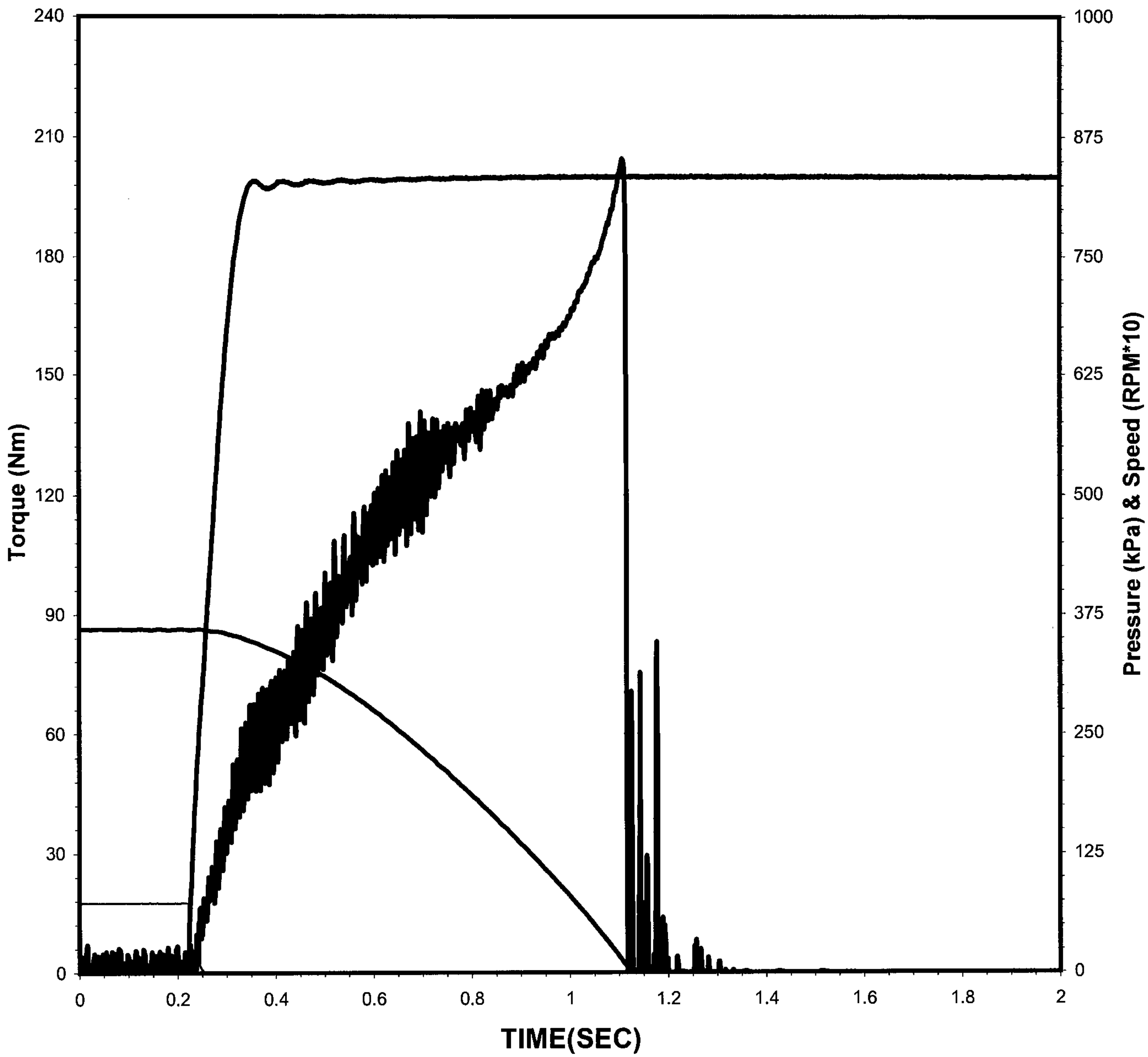
0.2 Sec Dyn: 56 N*m
Midpoint Dyn: 102 N*m
LwSpd Dynamic: 198 N*m

Coefficient of Friction

.2 Sec Dyn: 0.039
Midpoint Dyn: 0.071
LwSpd Dynamic: 0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test:	7/21/2010
Time of Test:	11:55:14
Test Number:	C4-7-1285
Fluid Code:	LO251746
Cycle Number:	5498
Temperature:	113.5 °C (112.7 ± 3.0 °C)
Apply Pressure:	832 kPa 827 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.4 KJ (18.71 ± 0.40 KJ)
Engage Time:	0.895 Sec

Torque

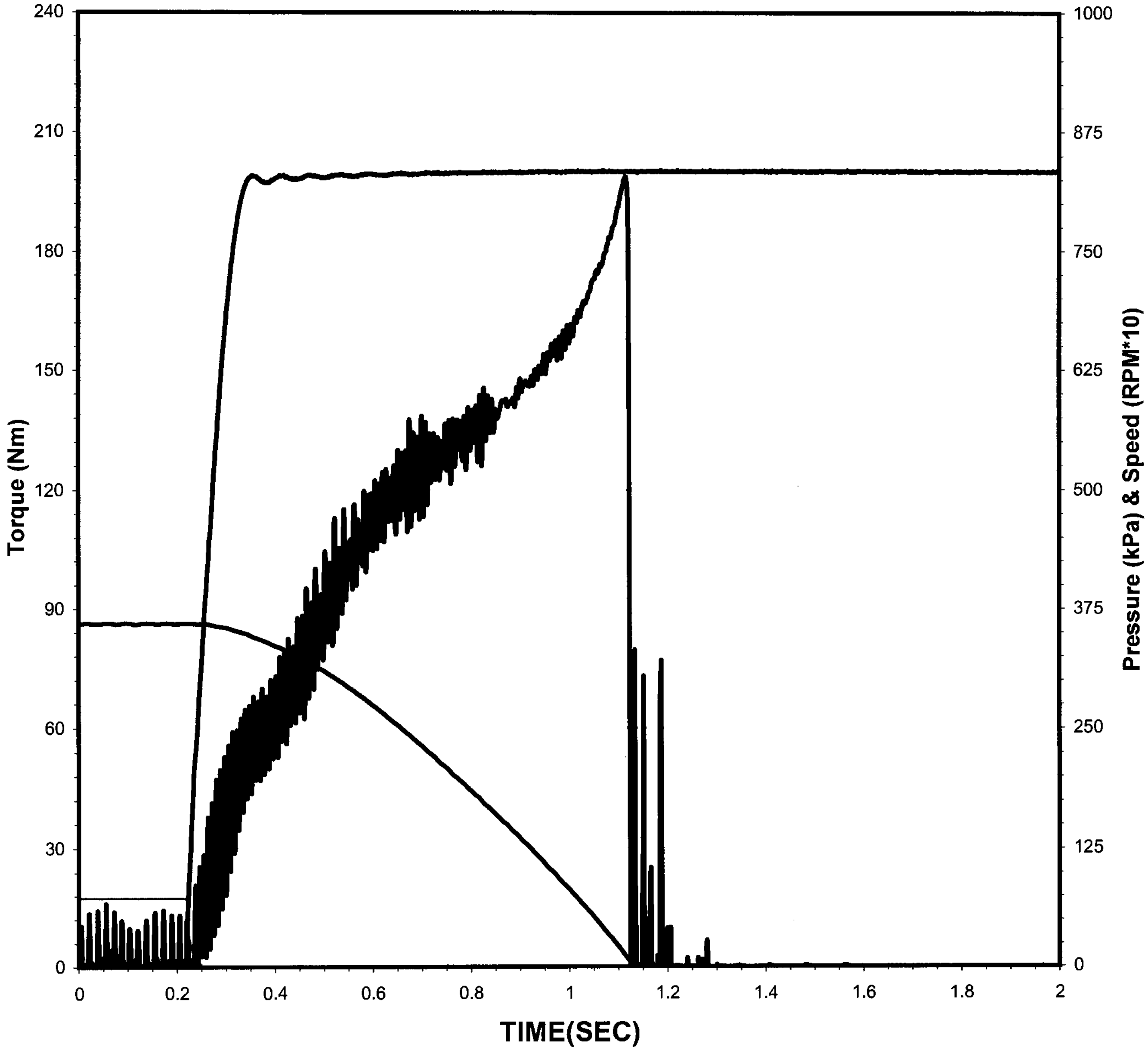
0.2 Sec Dyn:	70 N*m
Midpoint Dyn:	122 N*m
LwSpd Dynamic:	198 N*m

Coefficient of Friction

.2 Sec Dyn:	0.048
Midpoint Dyn:	0.084
LwSpd Dynamic:	0.137

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 11:55:29

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 5499

Temperature: 113.6 °C
(112.7 ± 3.0 °C)

Apply Pressure: 832 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.4 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.905 Sec

Torque

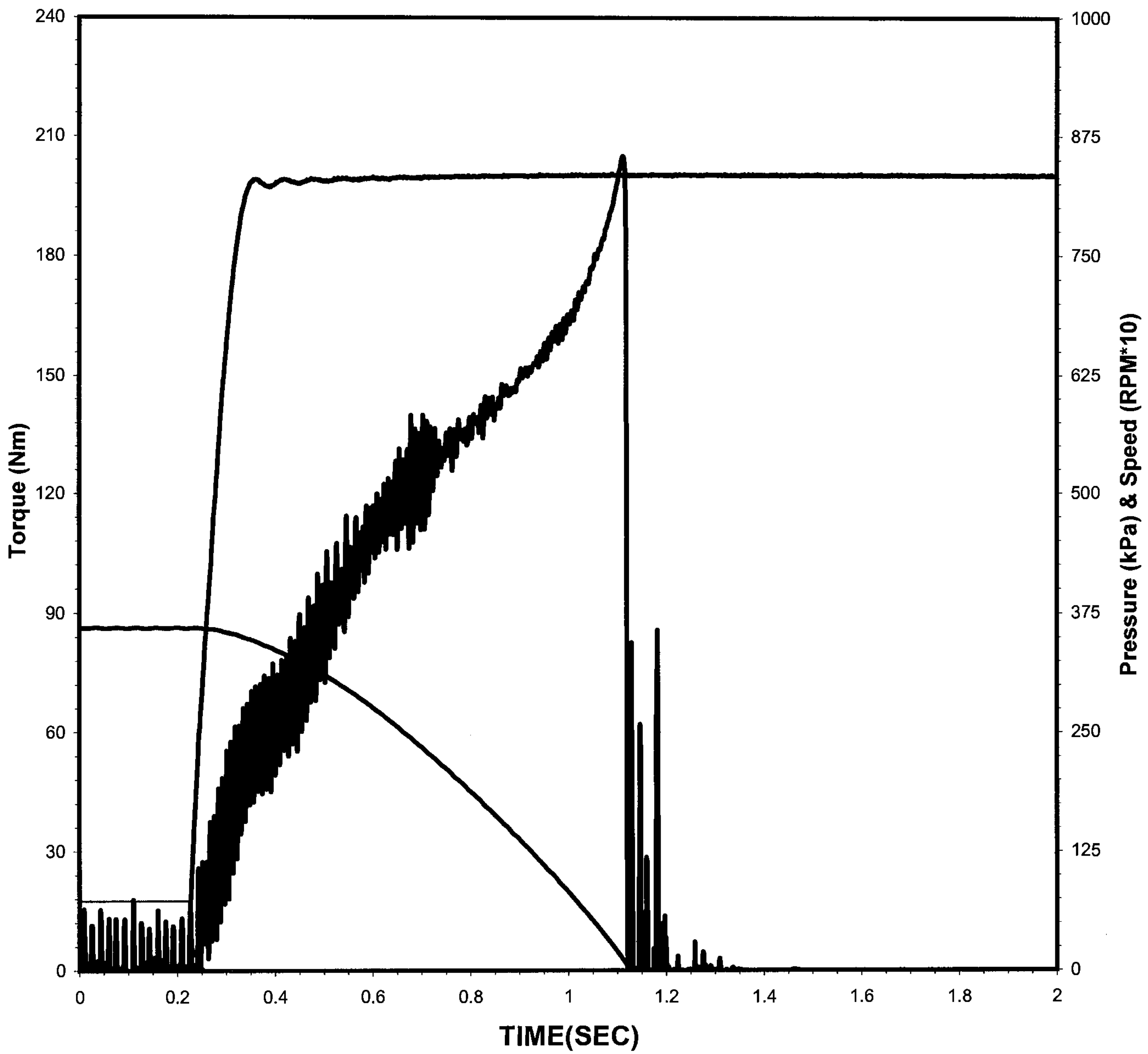
0.2 Sec Dyn:	68 N*m
Midpoint Dyn:	123 N*m
LwSpd Dynamic:	193 N*m

Coefficient of Friction

.2 Sec Dyn:	0.047
Midpoint Dyn:	0.085
LwSpd Dynamic:	0.134

ALLISON C-4 GRAPHITE DATA

DYNAMIC CYCLE PHASE B



Date of Test: 7/21/2010

Time of Test: 11:55:44

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 5500

Temperature: 113.7 °C
(112.7 ± 3.0 °C)

Apply Pressure: 832 kPa
827 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.3 KJ
(18.71 ± 0.40 KJ)

Engage Time: 0.898 Sec

Torque

0.2 Sec Dyn:	68 N*m
Midpoint Dyn:	122 N*m
LwSpd Dynamic:	197 N*m

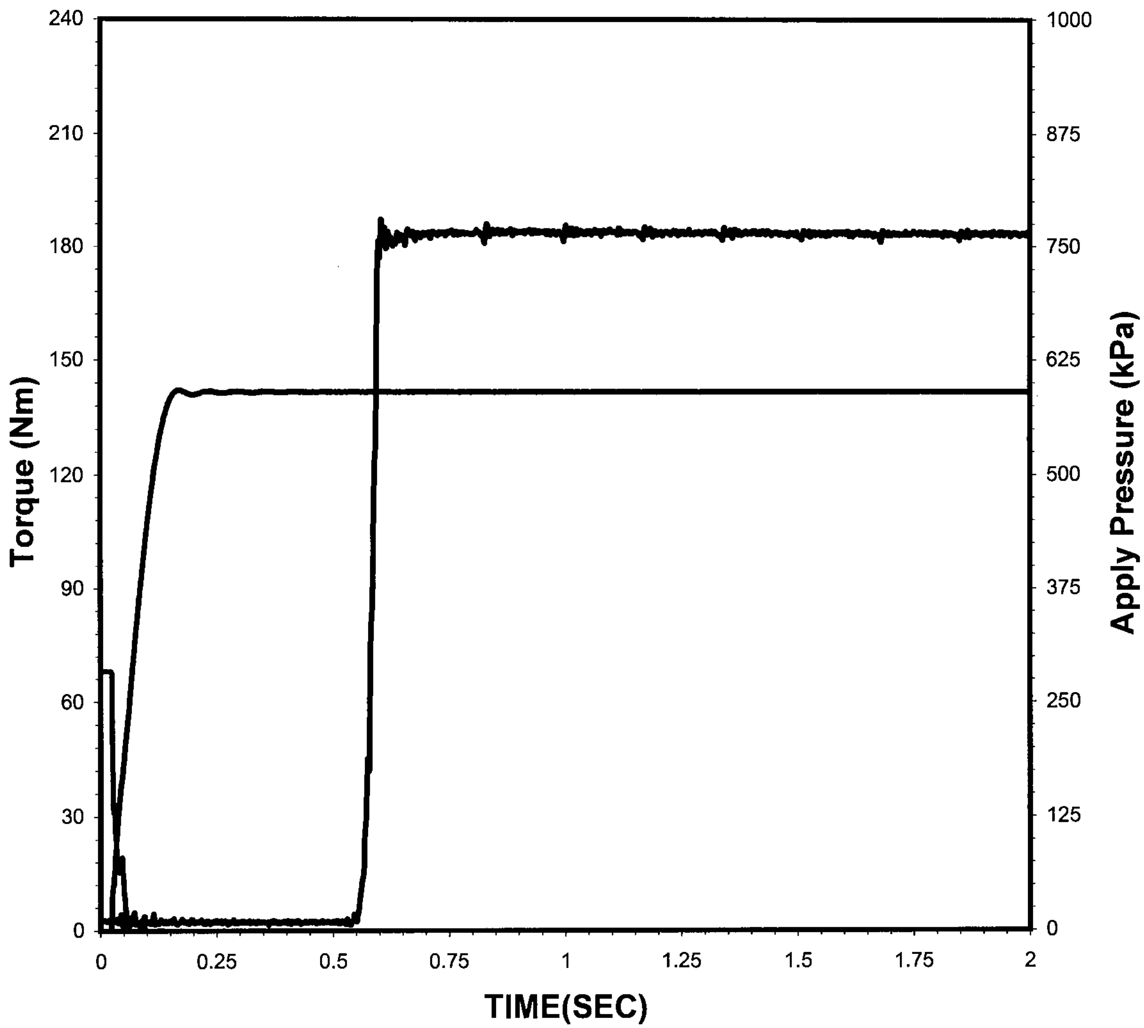
Coefficient of Friction

.2 Sec Dyn:	0.047
Midpoint Dyn:	0.084
LwSpd Dynamic:	0.136

STATIC TRACES

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 12:30:45

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 10

PHASE A

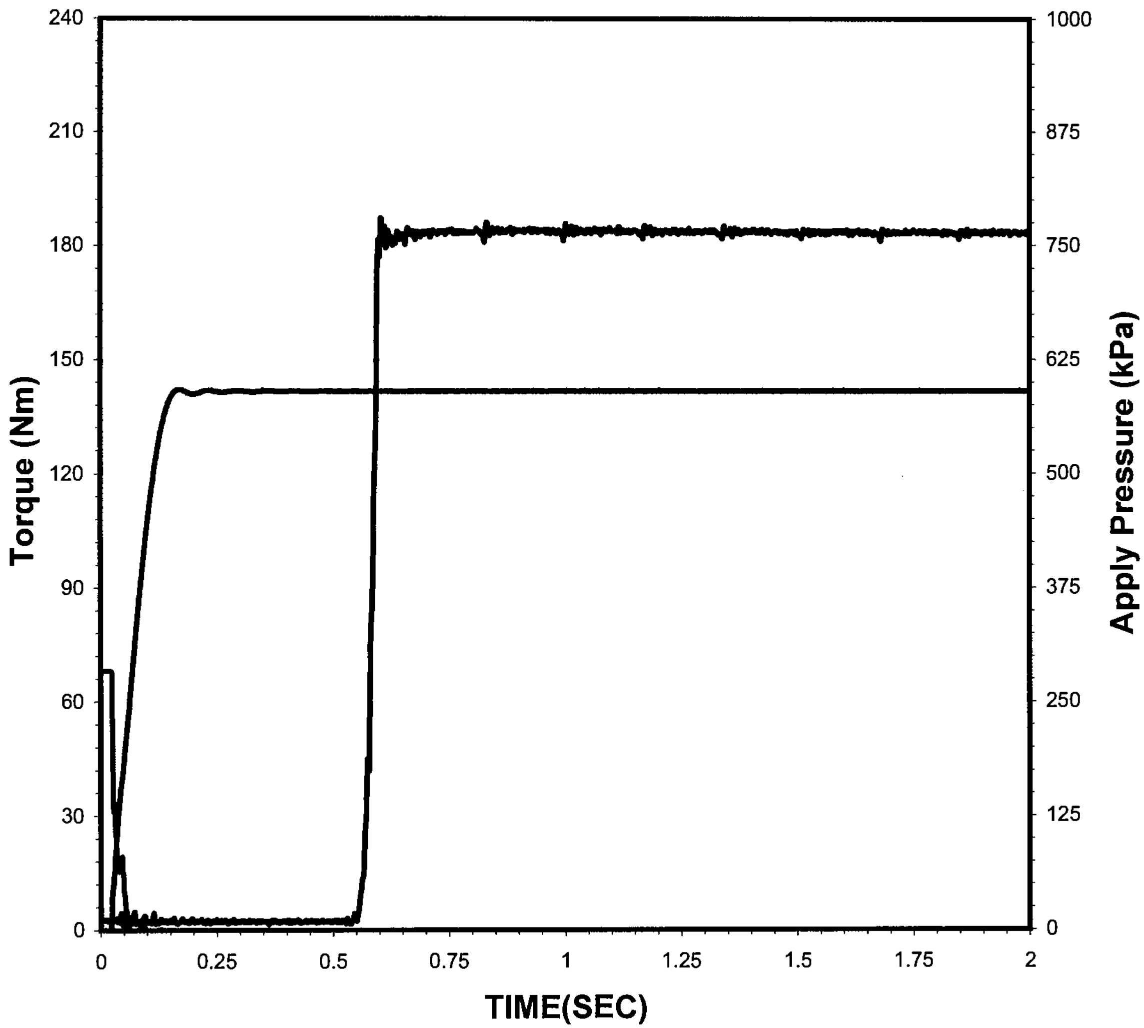
Apply Pressure:
At .25 Second: 348 kPa

Torque
Static Peak: 126 Nm
.25 Second: 98 Nm

Coefficient of Friction
Static Peak: 0.209
.25 Second: 0.163

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 14:33:26

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 500

PHASE A

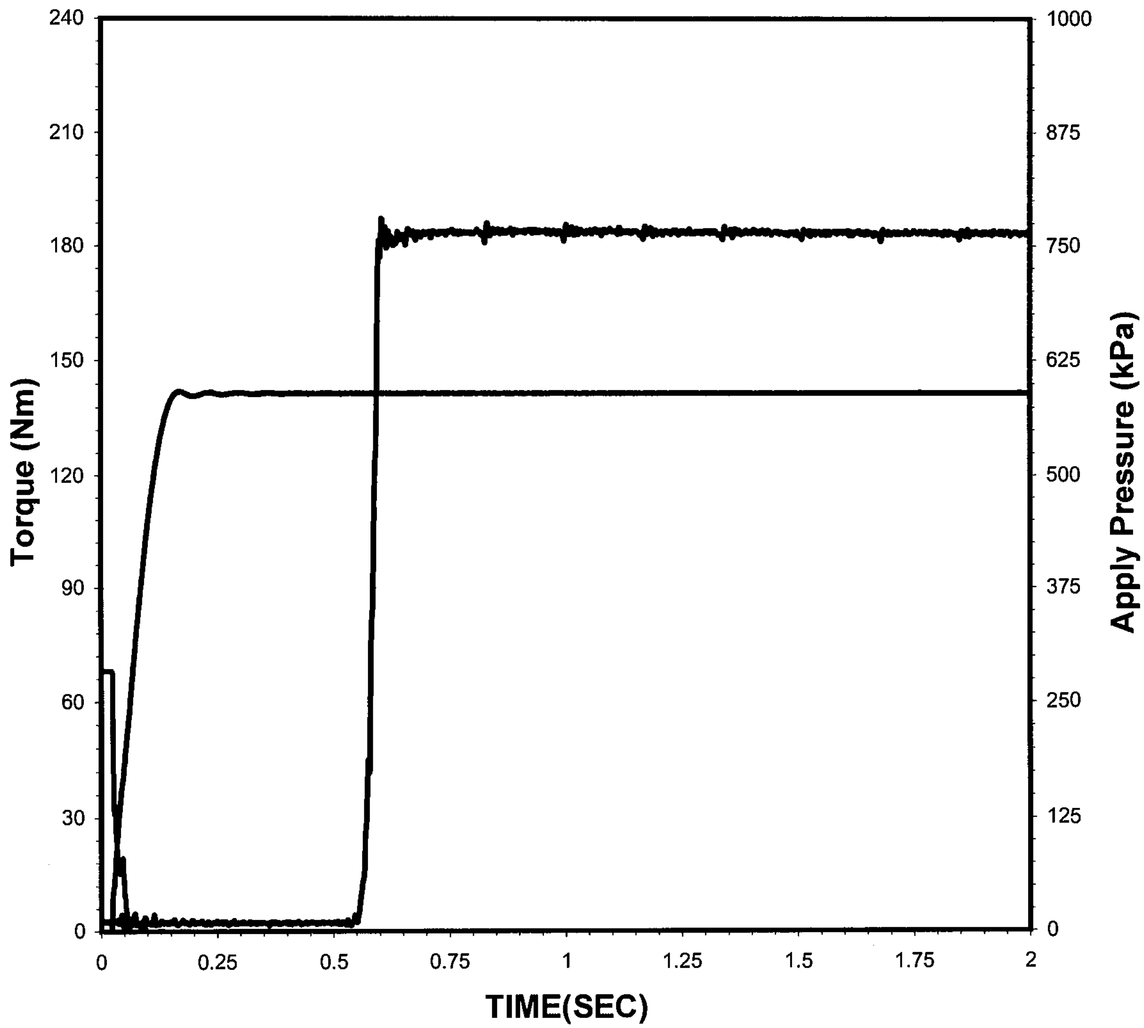
Apply Pressure:
At .25 Second: 348 kPa

Torque
Static Peak: 112 Nm
.25 Second: 102 Nm

Coefficient of Friction
Static Peak: 0.186
.25 Second: 0.169

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 16:38:38

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 1000

PHASE A

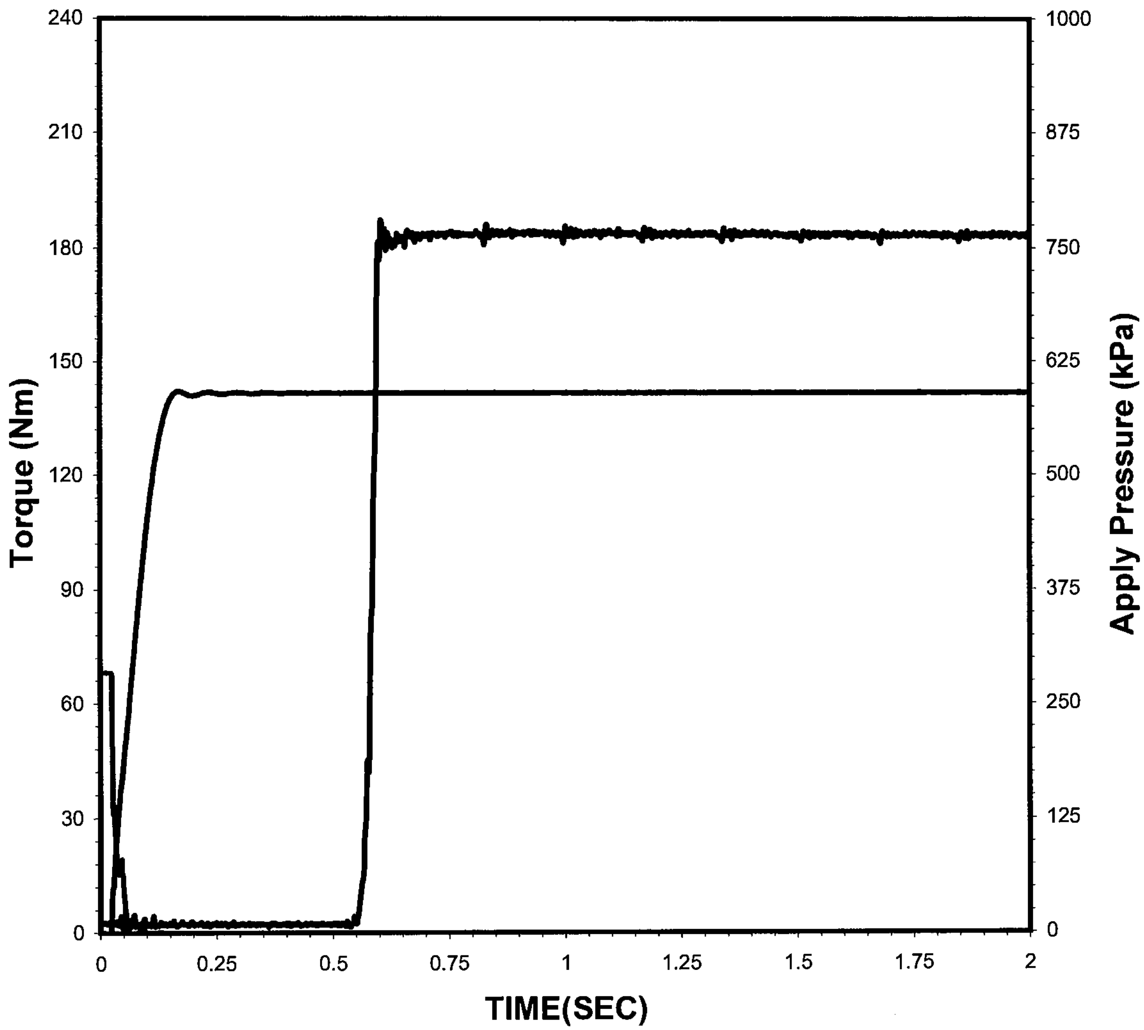
Apply Pressure:
At .25 Second: 349 kPa

Torque
Static Peak: 118 Nm
.25 Second: 99 Nm

Coefficient of Friction
Static Peak: 0.196
.25 Second: 0.165

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 19:02:04

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 1500

PHASE B

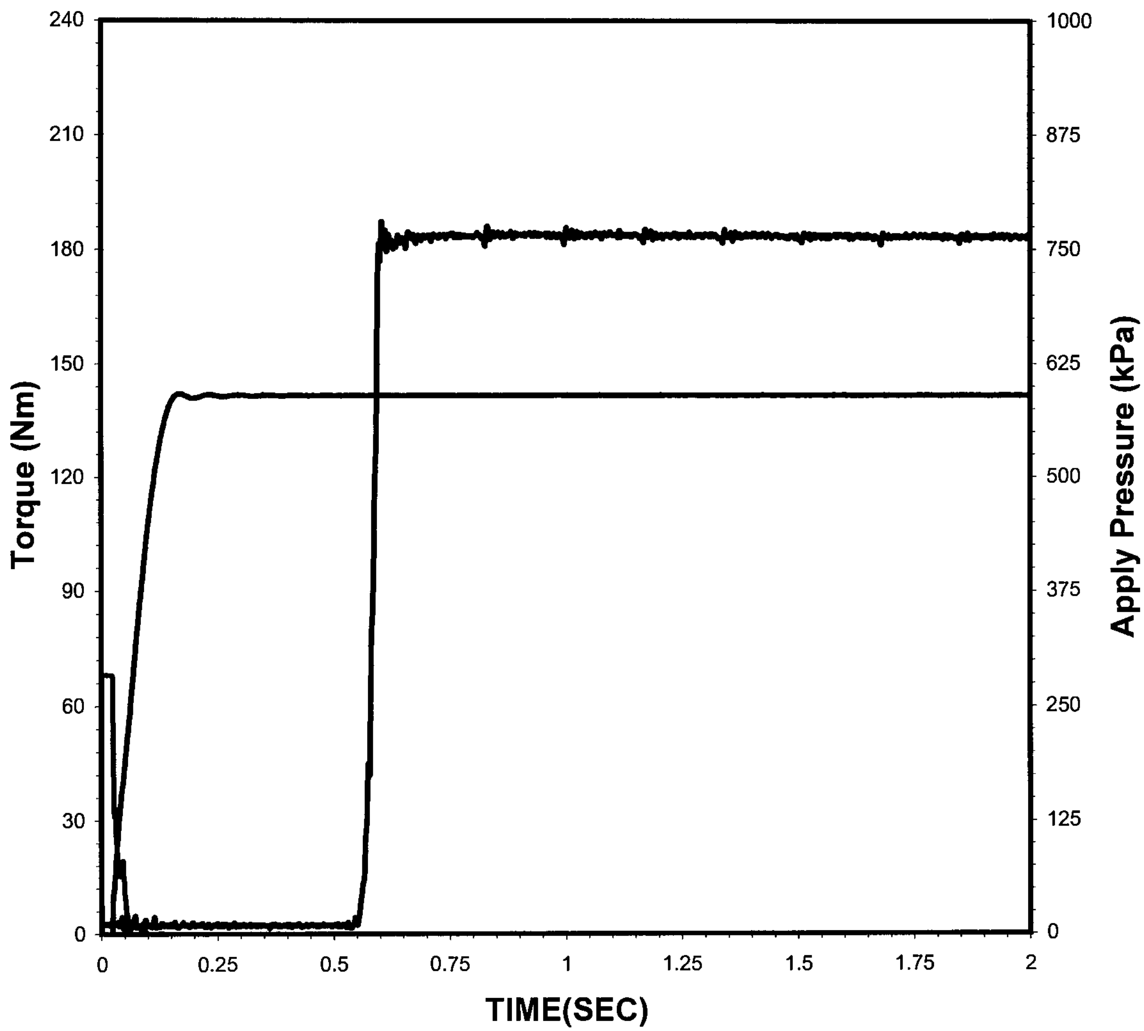
Apply Pressure:
At .25 Second: 830 kPa

Torque
Static Peak: 232 Nm
.25 Second: 216 Nm

Coefficient of Friction
Static Peak: 0.160
.25 Second: 0.149

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 21:07:16

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 2000

PHASE B

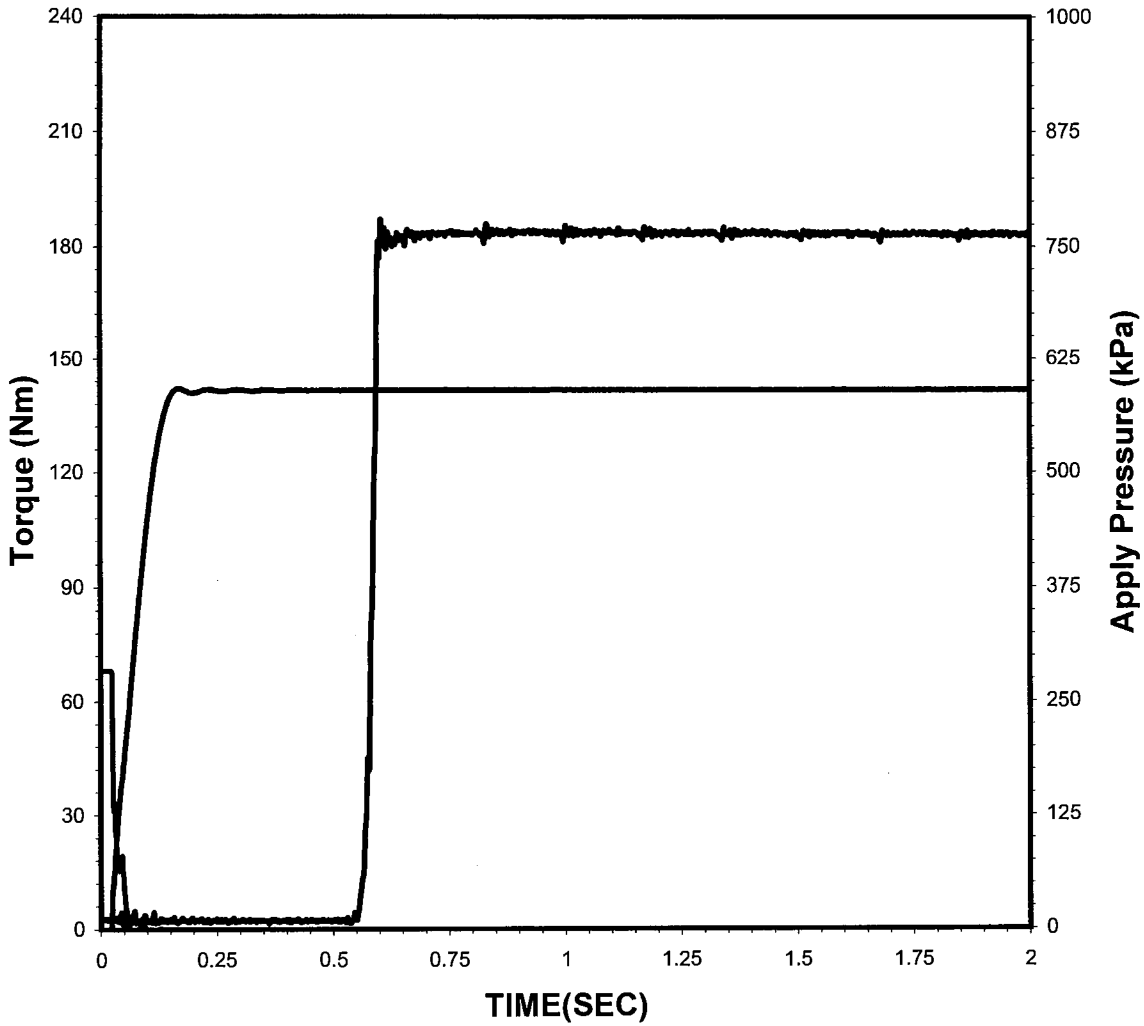
Apply Pressure:
At .25 Second: 831 kPa

Torque
Static Peak: 219 Nm
.25 Second: 214 Nm

Coefficient of Friction
Static Peak: 0.151
.25 Second: 0.148

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/20/2010

Time of Test: 23:24:45

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 2500

PHASE B

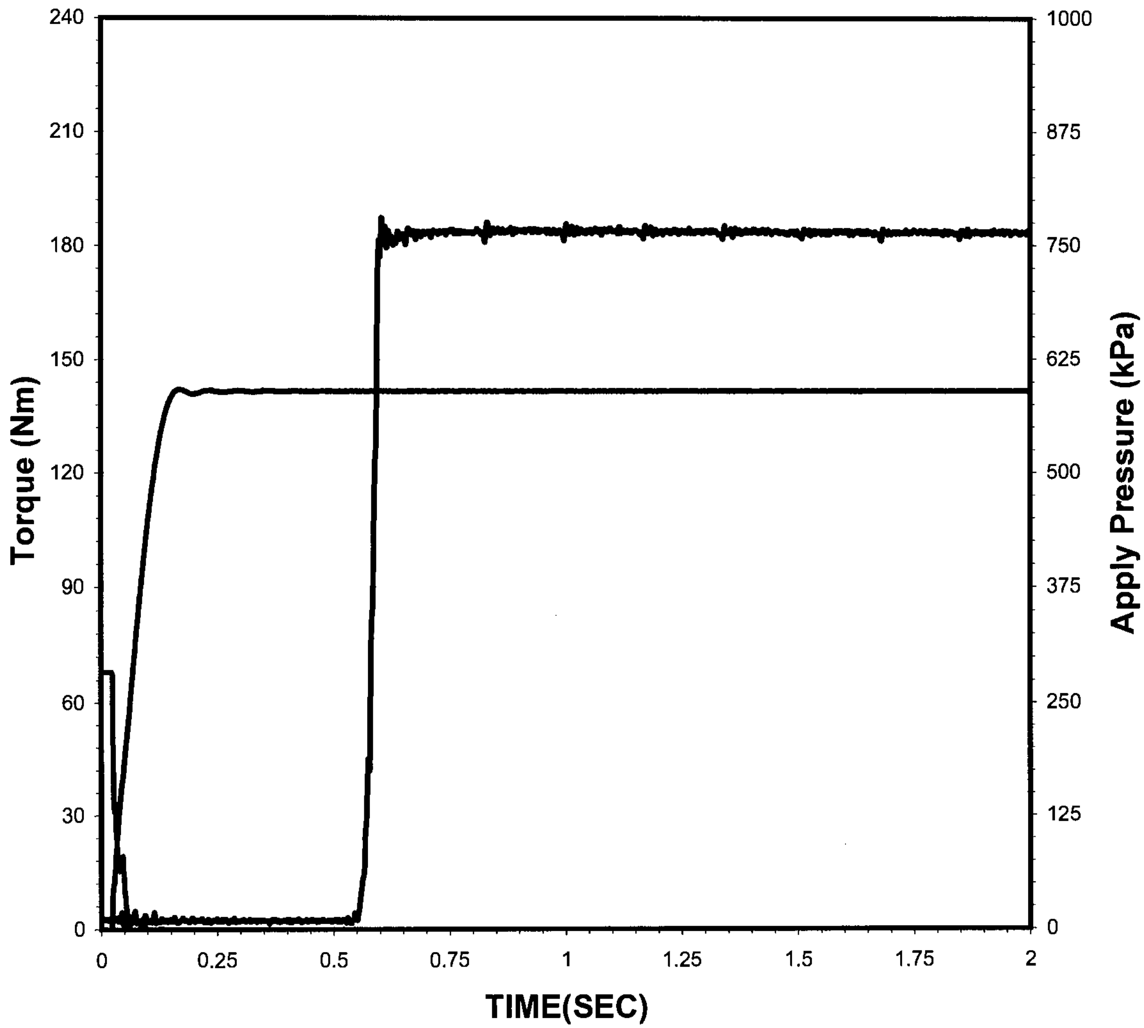
Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 228 Nm
.25 Second: 213 Nm

Coefficient of Friction
Static Peak: 0.157
.25 Second: 0.147

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 1:29:57

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 3000

PHASE B

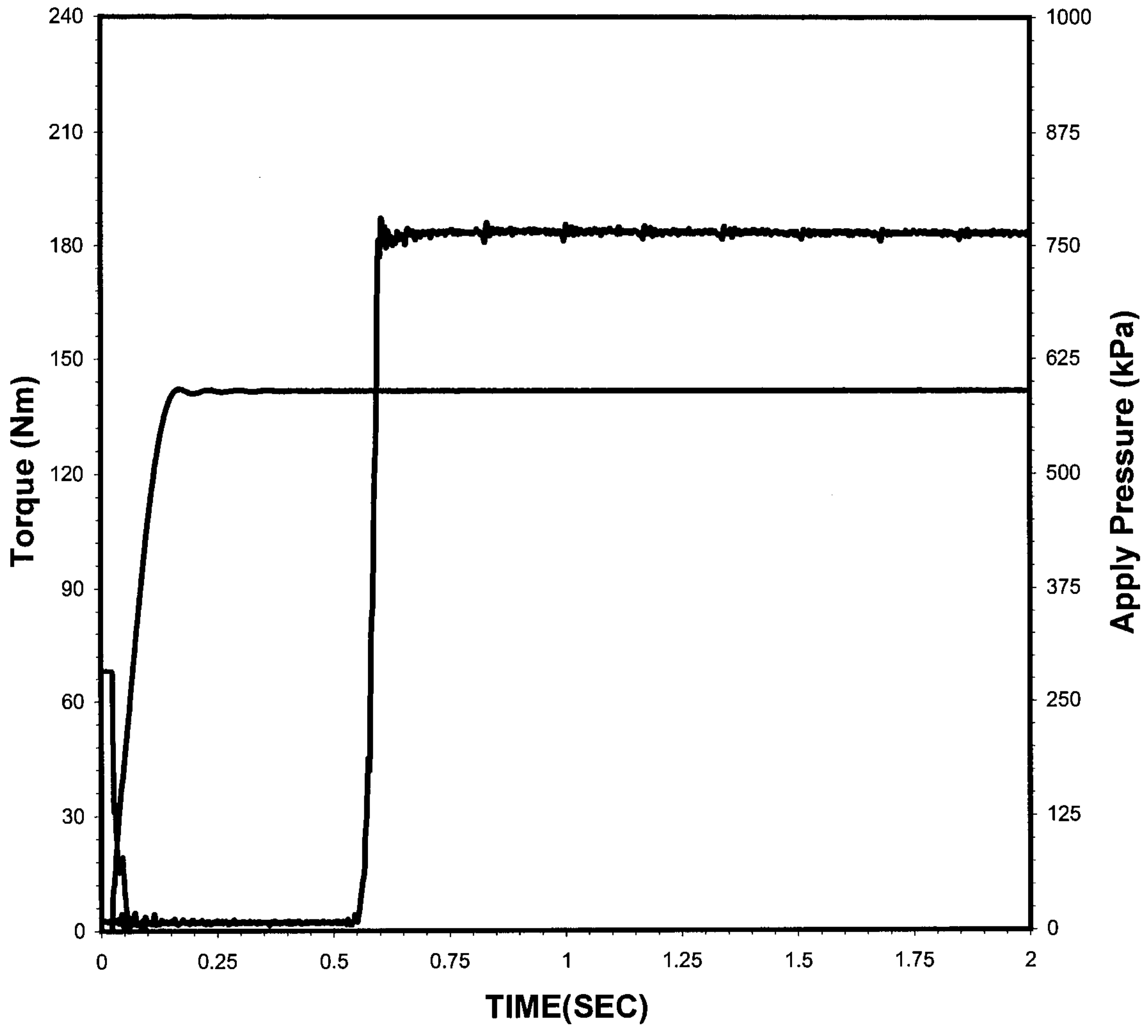
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 225 Nm
.25 Second: 210 Nm

Coefficient of Friction
Static Peak: 0.156
.25 Second: 0.145

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 3:35:08

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 3500

PHASE B

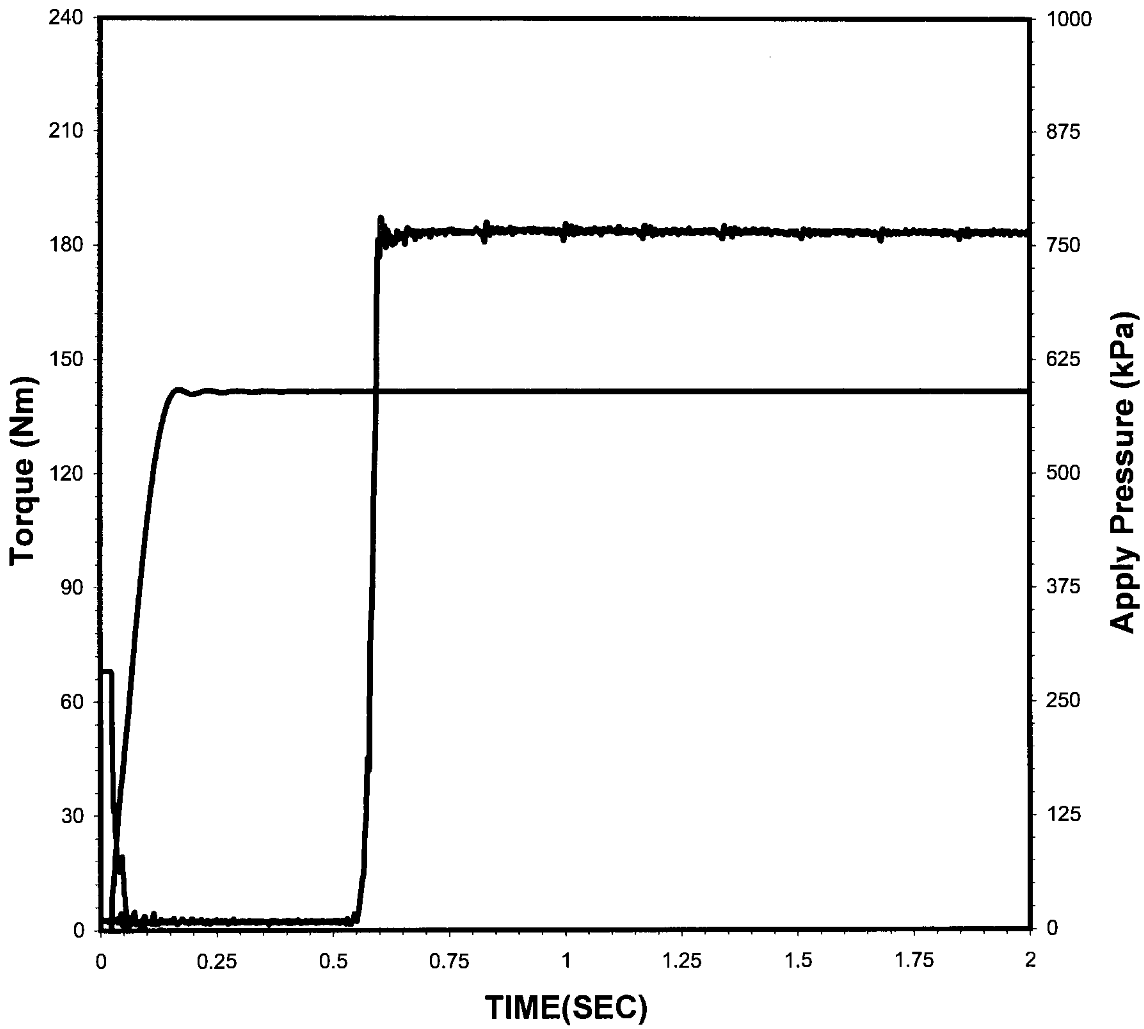
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 220 Nm
.25 Second: 210 Nm

Coefficient of Friction
Static Peak: 0.152
.25 Second: 0.145

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 5:40:20

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 4000

PHASE B

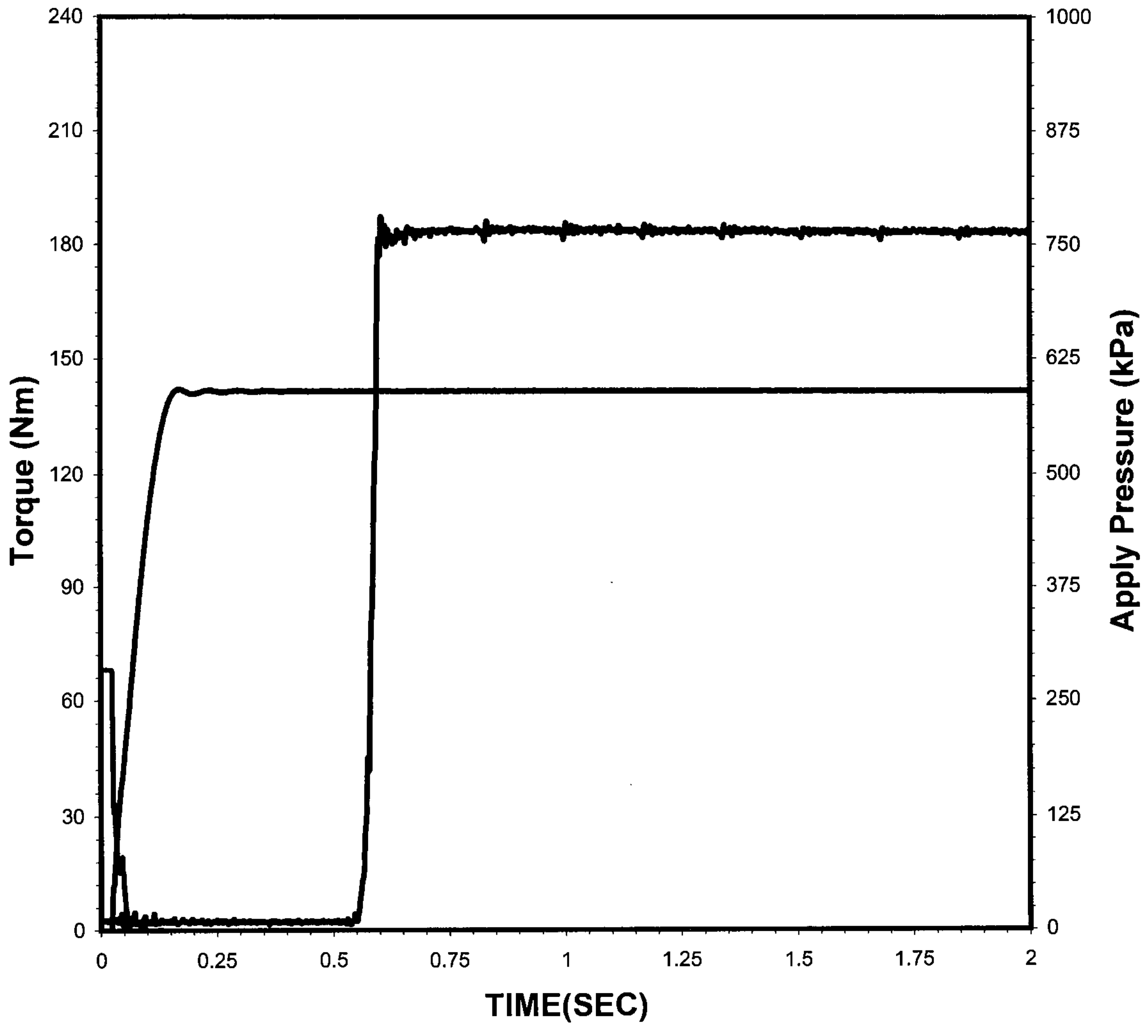
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 226 Nm
.25 Second: 209 Nm

Coefficient of Friction
Static Peak: 0.156
.25 Second: 0.144

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 7:45:32

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 4500

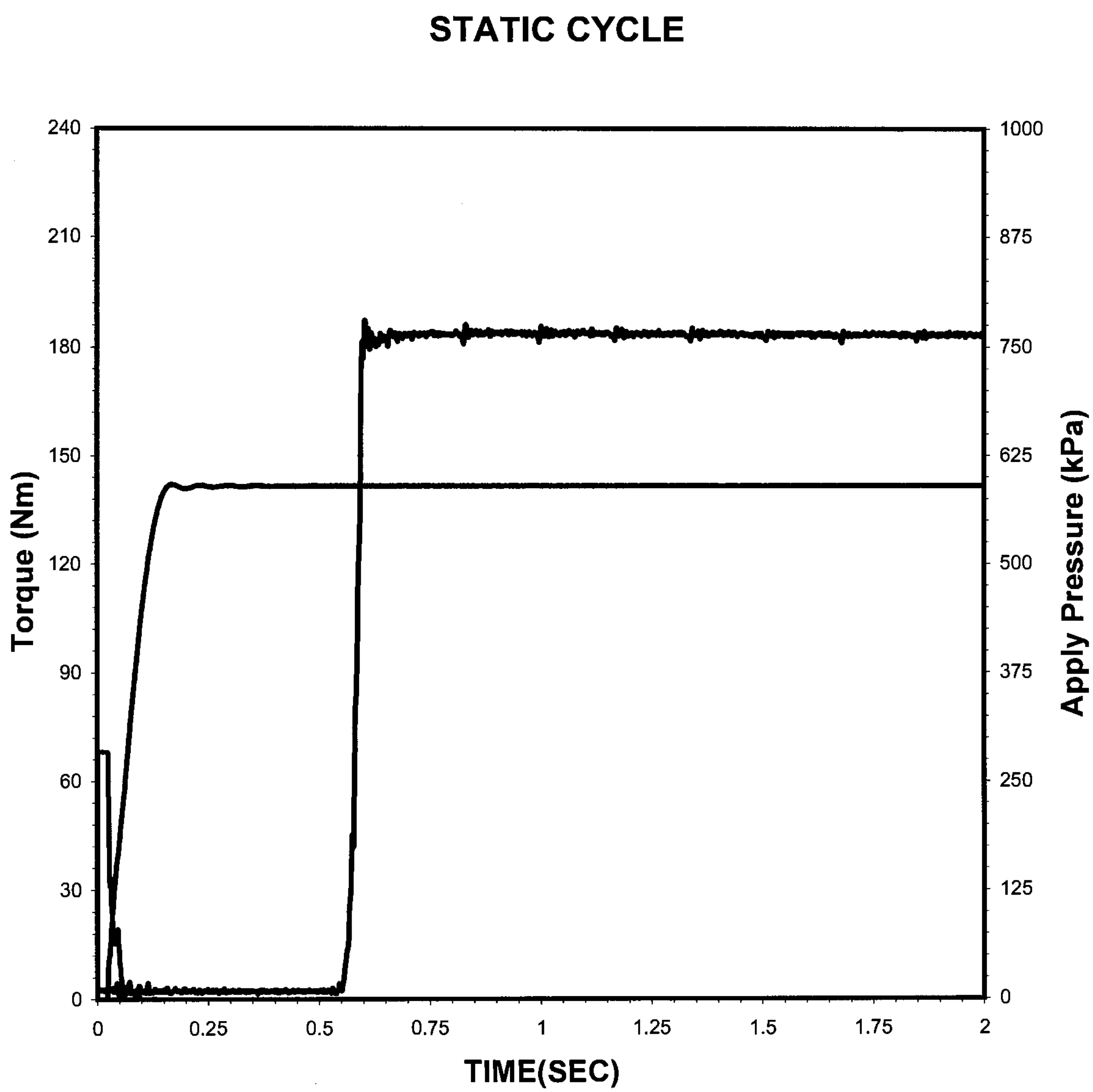
PHASE B

Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 234 Nm
.25 Second: 208 Nm

Coefficient of Friction
Static Peak: 0.162
.25 Second: 0.144

ALLISON C-4 GRAPHITE DATA



Date of Test: 7/21/2010

Time of Test: 9:50:44

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 5000

PHASE B

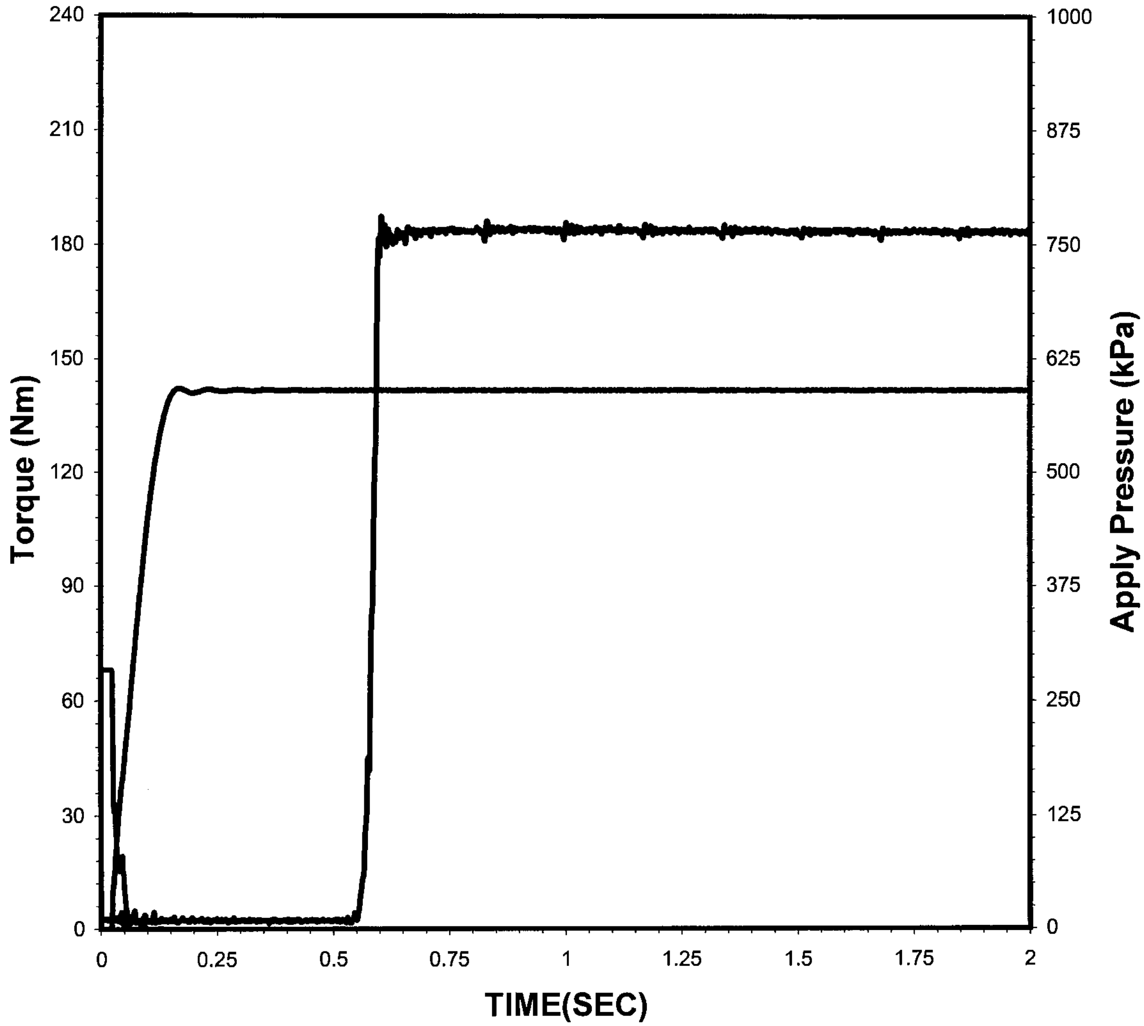
Apply Pressure:
At .25 Second: 833 kPa

Torque
Static Peak: 224 Nm
.25 Second: 208 Nm

Coefficient of Friction
Static Peak: 0.155
.25 Second: 0.144

ALLISON C-4 GRAPHITE DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 11:55:56

Test Number: C4-7-1285

Fluid Code: LO251746

Cycle Number: 5500

PHASE B

Apply Pressure:
At .25 Second: 832 kPa

Torque
Static Peak: 221 Nm
.25 Second: 206 Nm

Coefficient of Friction
Static Peak: 0.152
.25 Second: 0.142

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

ALLISON HYDRAULIC TRANSMISSION FLUID, TYPE C-4 PAPER CLUTCH FRICTION TEST

Conducted For

SWRI ARMY LAB

Oil Code:
LO-251746

Test Number:
C2-6-1551

July 23, 2010

Submitted by:

Matthew Jackson
Manager
Specialty & Driveline Fluids Evaluation

IX. Paper Clutch Friction Test

Test Laboratory:	SWRI	Lab Fluid Code:	LO-251746
Test Number:	C2-6-1551	Sponsor Fluid Code:	LO-251746
Friction Plate Batch:	BATCH 5	Completion Date:	07/23/10
Steel Plate Batch:	10/9/2008		

Clutch Wear Data
(units in mm)

	Maximum	Average
Steel Plates	0.0000	0.0000
Clutch Plate	0.0830	0.0718

	Before	After
Pack Clearance	1.1176	1.3970

Reference Tests

Test Number	Test Date	Test Fluid
C2-0-1523	01/24/09	RDL-2746 08-05
C2-0-1534	11/26/09	RDL-2746 08-05
C2-0-1545	04/03/10	RDL-2746 08-05

	New	EOT
Viscosity at 40°C, cSt	42.62	37.80
Viscosity at 100°C, cSt	8.14	7.44
Iron Content, ppm	2	185

D5185	New Fluid (ppm)
Ba	<1
B	72
Ca	807
Mg	1193
P	1058
Si	6
Na	6
Zn	1245

Name: Matthew Jackson

Signature:

Title: Manager

Date: 8/2/10

ALLISON C- 4 PAPER FRICTION TEST

(Torque in N*m)

Sponsor Fluid Code:	**LO-251746**	Test Number:	**C2-6-1551**
Lab Fluid Code:	**LO-251746**	Fric. Plate Batch:	**BATCH 5**
Completion Date:	**07/23/2010**	Steel Plate Batch:	**10/9/2008**

TORQUE

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.47	212	356	144	404	374
500	0.45	224	357	133	386	376
1000	0.44	231	353	122	375	365
2500	0.42	244	335	91	364	349
5000	0.42	247	331	84	348	341
7500	0.42	247	331	84	364	341
10000	0.42	247	328	81	356	339

COEFFICIENT OF FRICTION

CYCLE	SLIP TIME	TORQUE (MIDPOINT)	TORQUE STATIC PEAK	STATIC PEAK - MIDPOINT	LOW SPEED STATIC PEAK	LOWSPEED STATIC TORQUE
100	0.47	0.103	0.173	0.070	0.197	0.182
500	0.45	0.109	0.174	0.065	0.188	0.183
1000	0.44	0.112	0.172	0.060	0.183	0.178
2500	0.42	0.119	0.163	0.044	0.177	0.170
5000	0.42	0.120	0.161	0.041	0.169	0.166
7500	0.42	0.120	0.161	0.041	0.177	0.166
10000	0.42	0.120	0.160	0.040	0.173	0.165

	Limits		Results			
	Value	% Change	100 N	10,000 N	% Change	P/F
Slip Time Max.	0.600	N/A	0.470	0.420	-10.64	P
Mid-Point Fric. Coeff. Min.	0.096	N/A	0.103	0.120	16.50	P
Static Friction Coeff.	N/A	N/A	0.173	0.160	-7.51	
Low Speed Peak Fric. Coeff.	N/A	N/A	0.197	0.173	-12.18	
0.25 Second Low Speed Coeff.	N/A	N/A	0.182	0.165	-9.34	

SOUTHWEST RESEARCH INSTITUTE®

ALLISON C4-PAPER FRICTION TEST

(all units in mm)

Candidate Fluid: LO251746 **Test Number : C2-6-1551** **Completion Date : 7/23/2010**

Lab Fluid Code : LO-251746 **Steel Plate Batch: 10/09/2008** **Fric Plate Batch : LOT 5**

Plates	Location of Tooth (Clockwise)	Near Inner Diameter Before	Near Inner Diameter After	Near Outer Diameter Before	Near Outer Diameter After	Inner Diameter Change	Average Overall Change	Outer Diameter Change
FRICTION MATERIAL								
2	Top	2.0400	1.9570	2.0410	1.9650	0.0830		0.0760
	120	2.0290	1.9490	2.0170	1.9500	0.0800		0.0670
	240	2.0230	1.9520	2.0220	1.9520	0.0710		0.0700
	Average					0.0780	0.0745	0.0710
5	Top	2.0570	1.9740	2.0530	1.9780	0.0830		0.0750
	120	2.0530	1.9820	2.0380	1.9850	0.0710		0.0530
	240	2.0490	1.9760	2.0370	1.9780	0.0730		0.0590
	Average					0.0757	0.0690	0.0623
STEELS SEPARATORS								
1	Top	1.7580	1.7580	1.7580	1.7580	0.0000		0.0000
	120	1.7580	1.7580	1.7560	1.7560	0.0000		0.0000
	240	1.7560	1.7560	1.7560	1.7560	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
3	Top	1.7500	1.7500	1.7530	1.7530	0.0000		0.0000
	120	1.7530	1.7530	1.7540	1.7540	0.0000		0.0000
	240	1.7530	1.7530	1.7540	1.7540	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
4	Top	1.7590	1.7590	1.7590	1.7590	0.0000		0.0000
	120	1.7580	1.7580	1.7560	1.7560	0.0000		0.0000
	240	1.7560	1.7560	1.7550	1.7550	0.0000		0.0000
	Average					0.0000	0.0000	0.0000
6	Top	1.7600	1.7600	1.7600	1.7600	0.0000		0.0000
	120	1.7590	1.7590	1.7580	1.7580	0.0000		0.0000
	240	1.7610	1.7610	1.7610	1.7610	0.0000		0.0000
	Average					0.0000	0.0000	0.0000

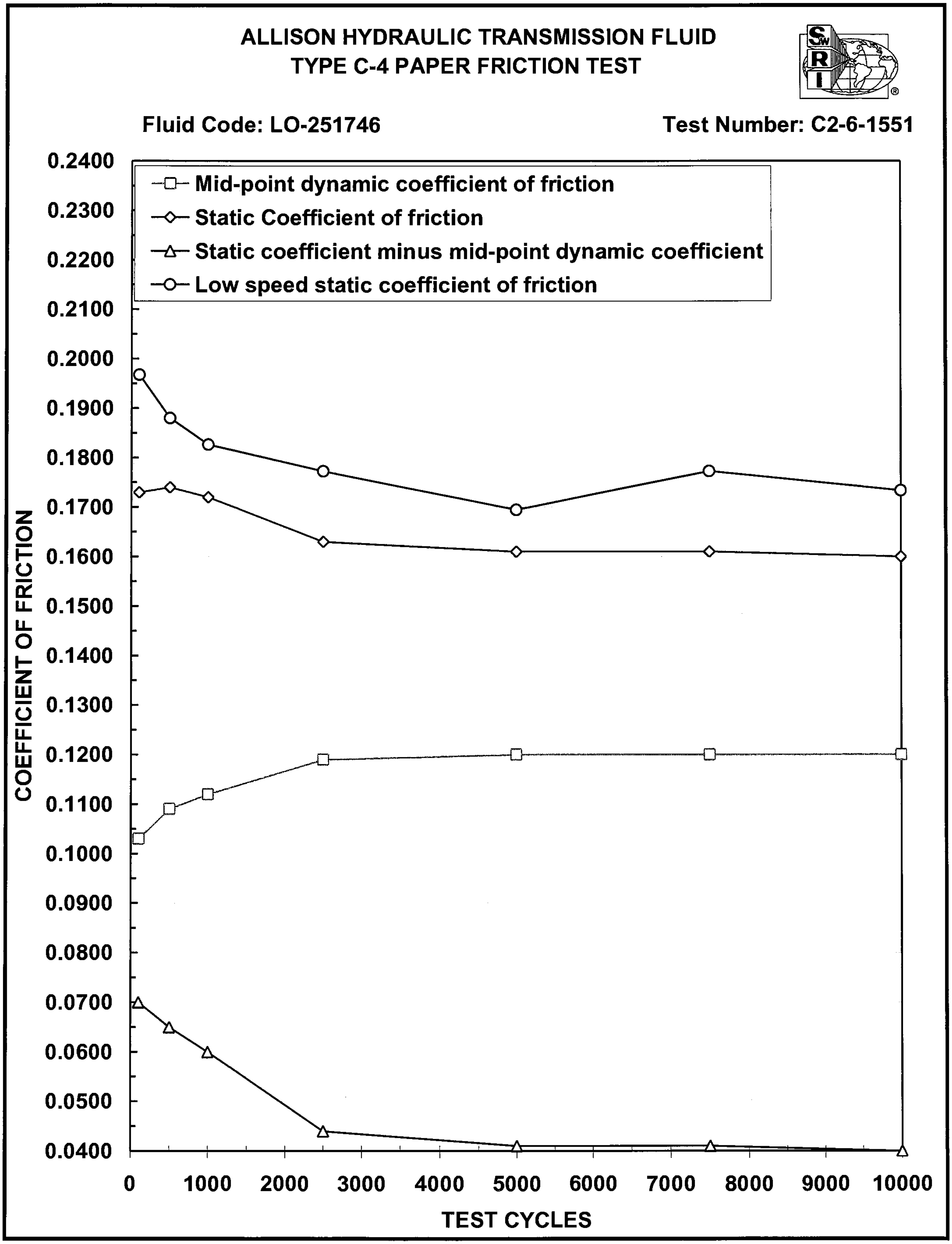
PLATE CONDITION AT E.O.T.: PLATES IN GOOD CONDITION
(Anything Unusual)

Test Date and Operator's Name: 7/23/2010 JOE M

Reviewed By (Signature and Date)

8/2/10

Pack ID#: 4410

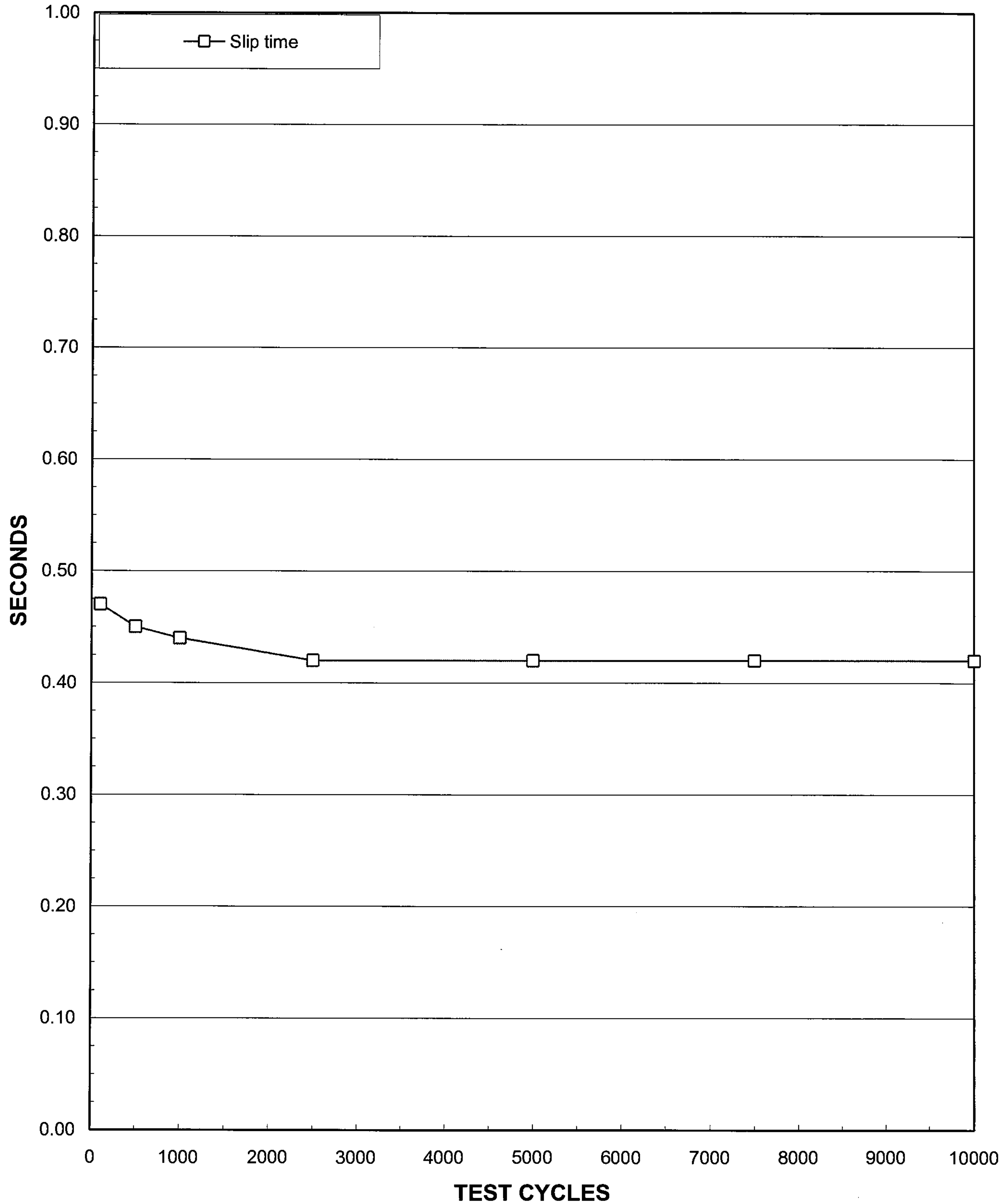


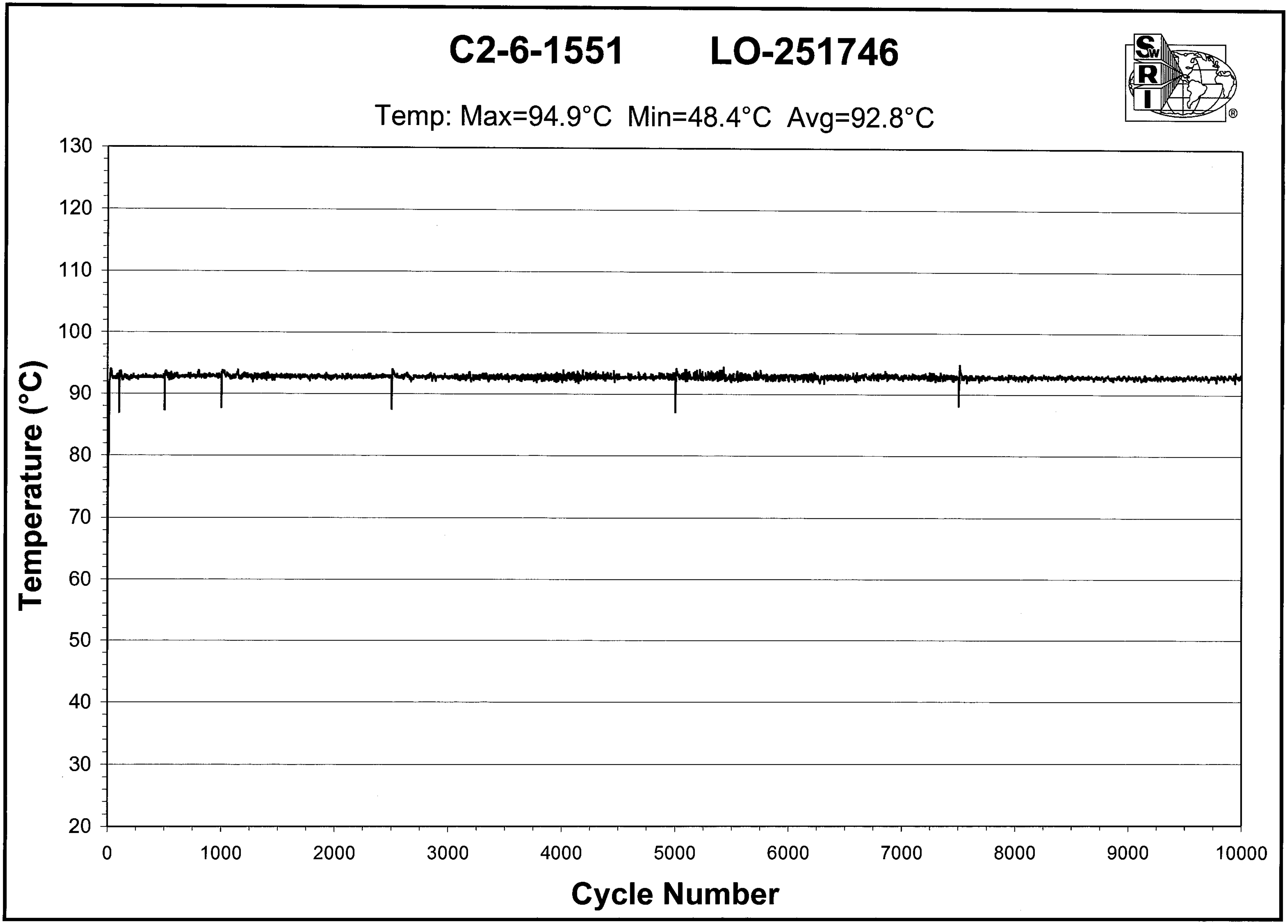
ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST
Fluid Code: LO-251746
Test Number: C2-6-1551
Mid-point dynamic coefficient of friction
Static Coefficient of friction
Static coefficient minus mid-point dynamic coefficient
Low speed static coefficient of friction
COEFFICIENT OF FRICTION
0.2400
0.2300
0.2200
0.2100
0.2000
0.1900
0.1800
0.1700
0.1600
0.1500
0.1400
0.1300
0.1200
0.1100
0.1000
0.0900
0.0800
0.0700
0.0600
0.0500
0.0400
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
TEST CYCLES

ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-4 PAPER FRICTION TEST

Fluid Code: LO-251746

Test Number: C2-6-1551



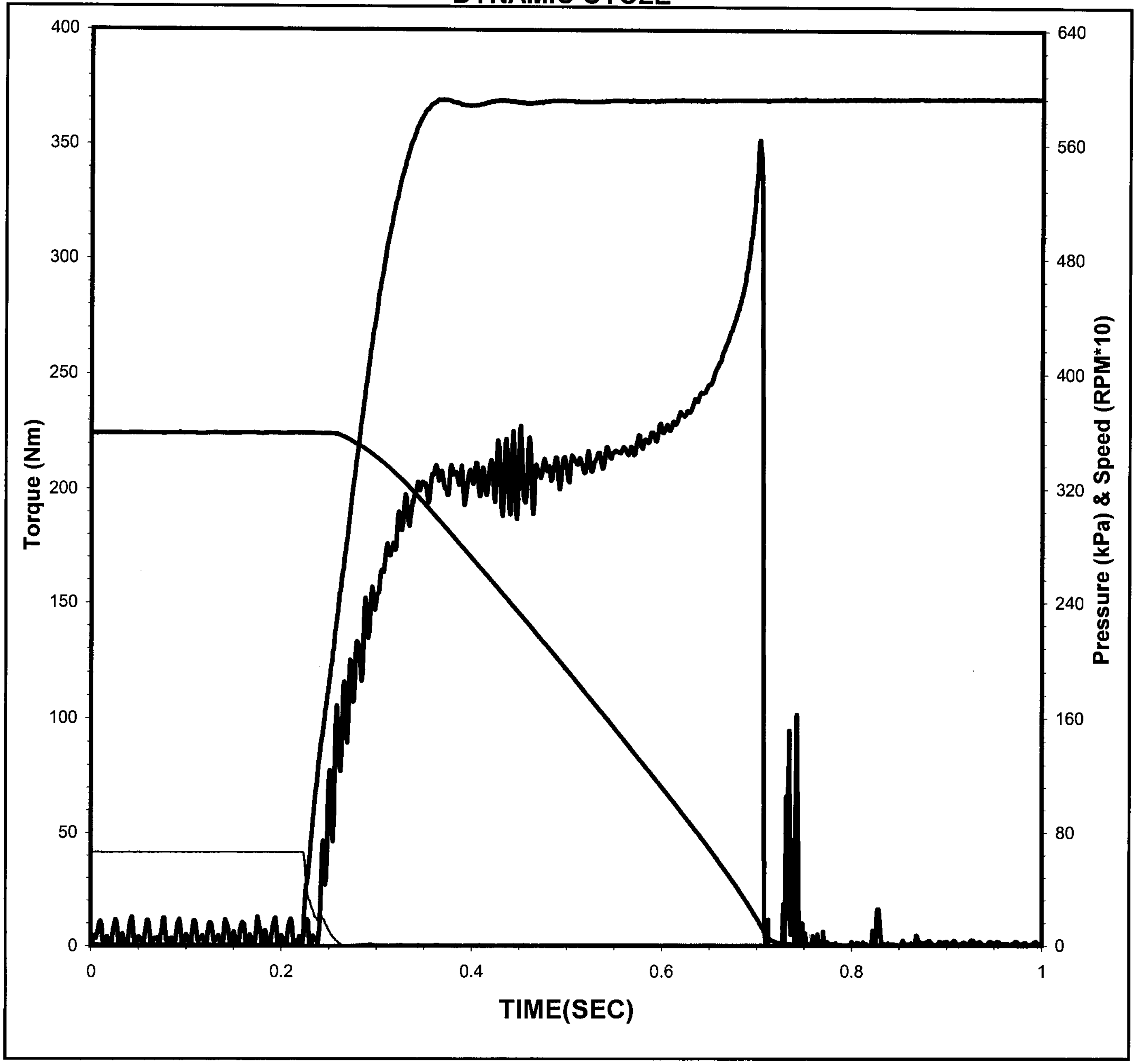


C2-6-1551
LO-251746
Temp: Max=94.9°C Min=48.4°C Avg=92.8°C
Temperature (°C)
130
120
110
100
90
80
70
60
50
40
30
20
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Cycle Number

DYNAMIC TRACES

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/21/2010
Time of Test:	8:22:03
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	10
Temperature:	83.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.485 Sec

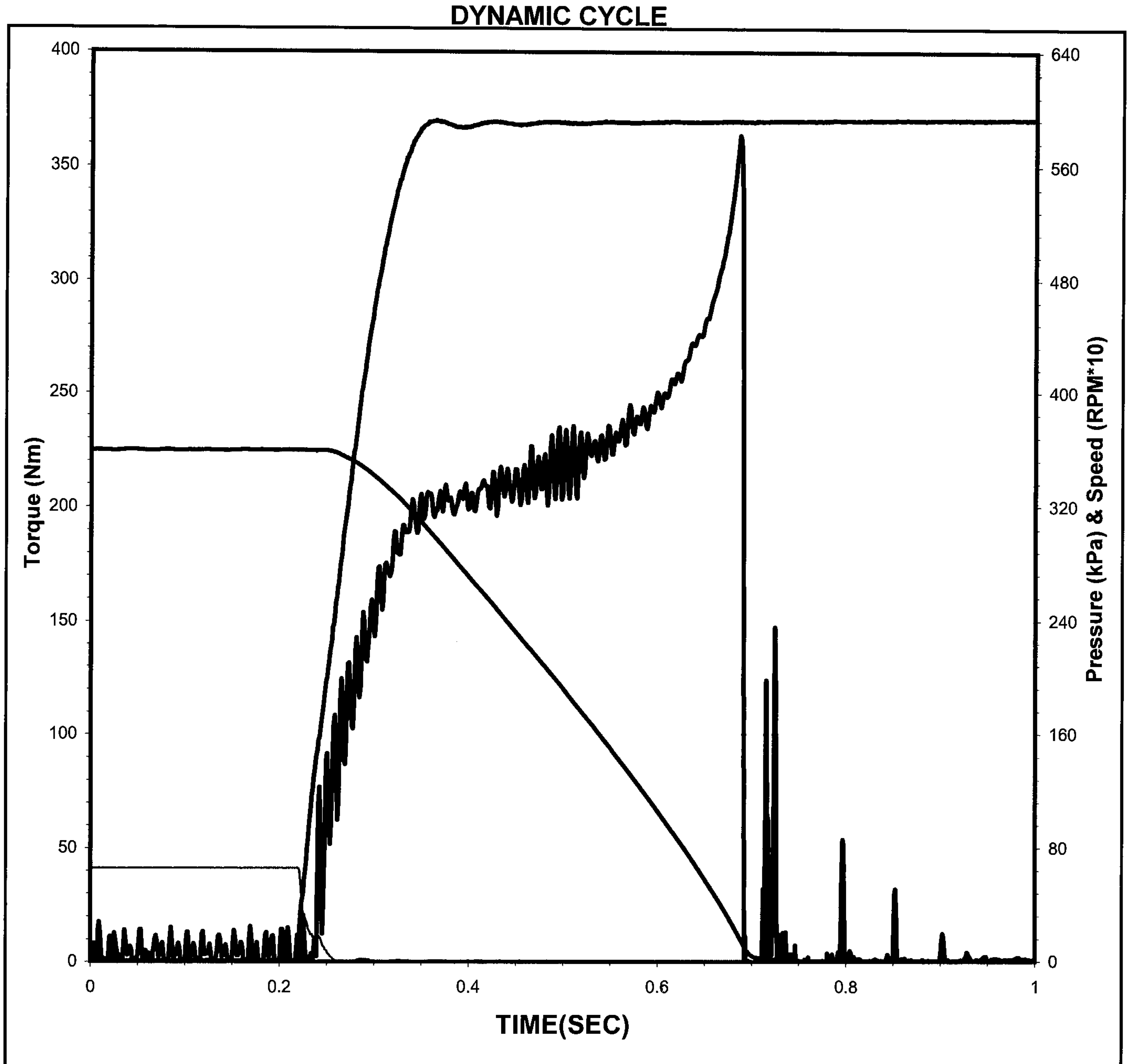
Torque

0.2 Sec Dyn:	204 N*m
Midpoint Dyn:	206 N*m
LwSpd Dynamic:	343 N*m

Coefficient of Friction

.2 Sec Dyn:	0.099
Midpoint Dyn:	0.100
LwSpd Dynamic:	0.167

ALLISON C-4 PAPER DATA



Date of Test:	7/21/2010
Time of Test:	8:44:35
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	99
Temperature:	92.2 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.5 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.471 Sec

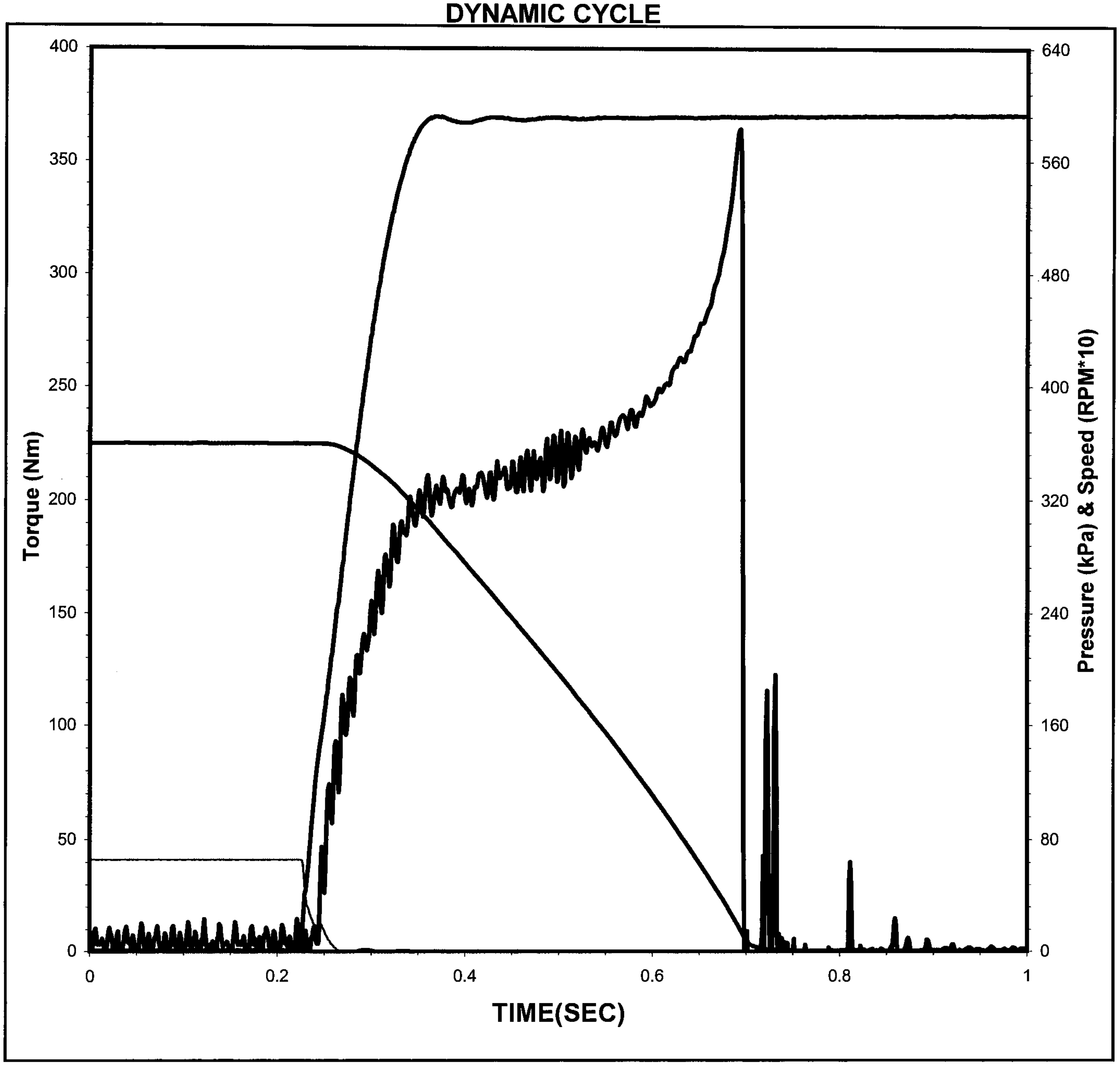
Torque

0.2 Sec Dyn:	206 N*m
Midpoint Dyn:	211 N*m
LwSpd Dynamic:	355 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.103
LwSpd Dynamic:	0.173

ALLISON C-4 PAPER DATA



Date of Test:	7/21/2010
Time of Test:	8:44:50
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	100
Temperature:	92.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.471 Sec

Torque

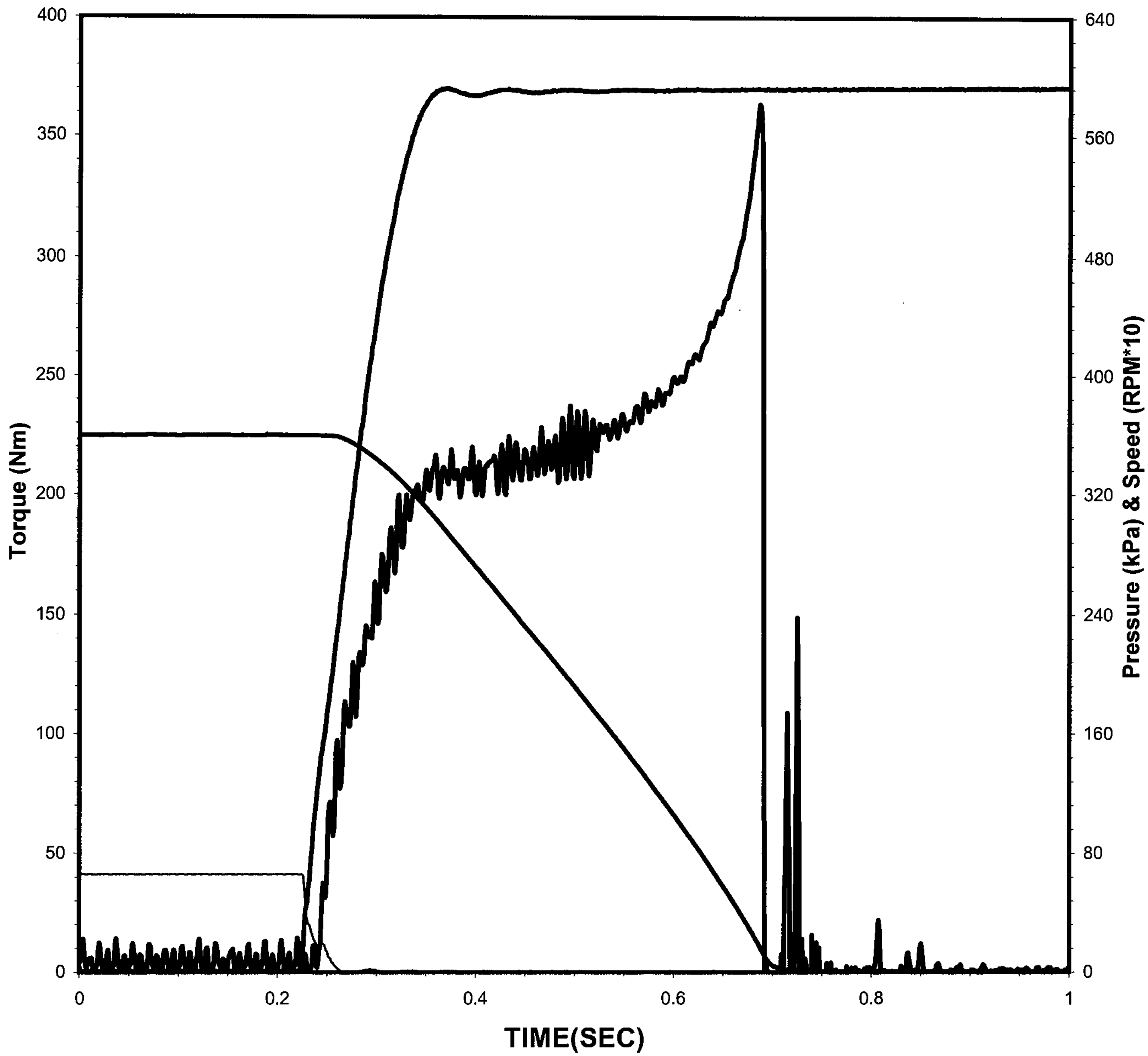
0.2 Sec Dyn:	206 N*m
Midpoint Dyn:	210 N*m
LwSpd Dynamic:	354 N*m

Coefficient of Friction

.2 Sec Dyn:	0.100
Midpoint Dyn:	0.102
LwSpd Dynamic:	0.172

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/21/2010

Time of Test: 8:45:21

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 101

Temperature: 86.8 °C
(93.3 ± 3.0 °C)

Apply Pressure: 589 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.466 Sec

Torque

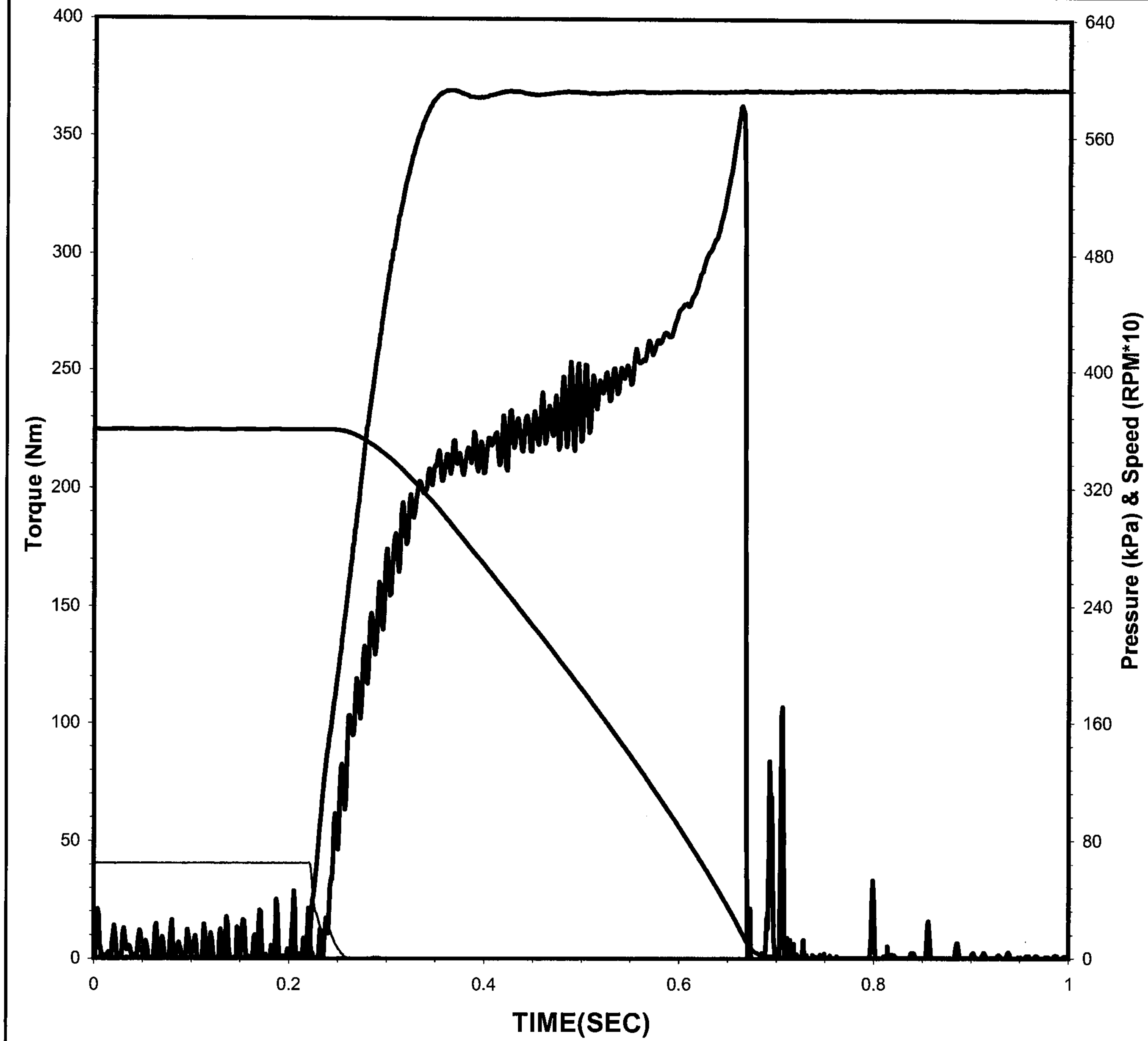
0.2 Sec Dyn:	211 N*m
Midpoint Dyn:	214 N*m
LwSpd Dynamic:	358 N*m

Coefficient of Friction

.2 Sec Dyn:	0.103
Midpoint Dyn:	0.104
LwSpd Dynamic:	0.174

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/21/2010
Time of Test:	10:24:51
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	499
Temperature:	92.7 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.449 Sec

Torque

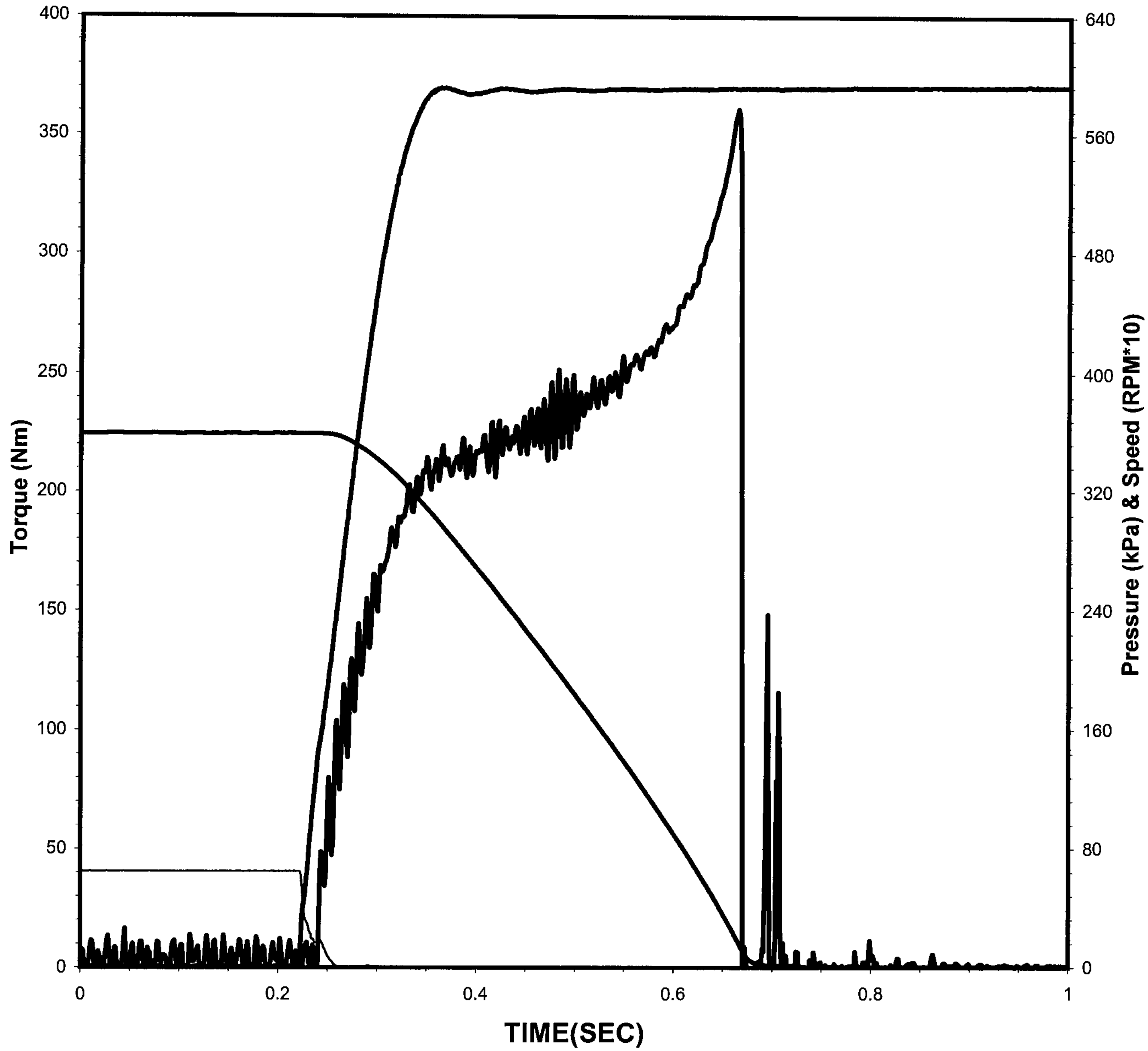
0.2 Sec Dyn:	220 N*m
Midpoint Dyn:	224 N*m
LwSpd Dynamic:	360 N*m

Coefficient of Friction

.2 Sec Dyn:	0.107
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.175

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/21/2010**
Time of Test:	**10:25:06**
Test Number:	**C2-6-1551**
Fluid Code:	**LO-251746**
Cycle Number:	**500**
Temperature:	**92.5 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**589 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.5 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.447 Sec**

Torque

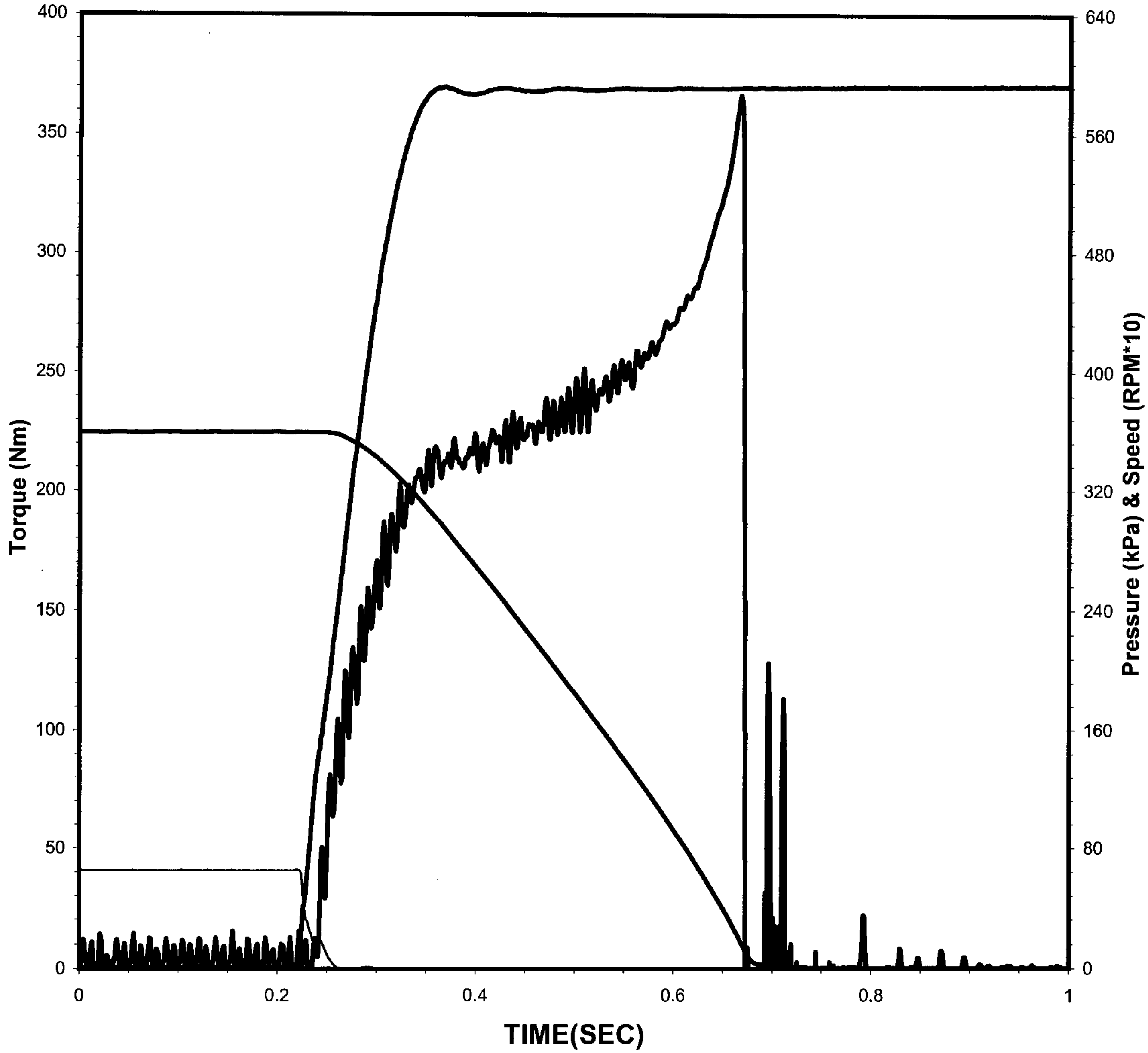
0.2 Sec Dyn:	**221 N*m**
Midpoint Dyn:	**224 N*m**
LwSpd Dynamic:	**352 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.107**
Midpoint Dyn:	**0.109**
LwSpd Dynamic:	**0.172**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/21/2010
Time of Test:	10:25:37
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	501
Temperature:	87.2 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	589 kPa
	(586 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.7 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.449 Sec

Torque

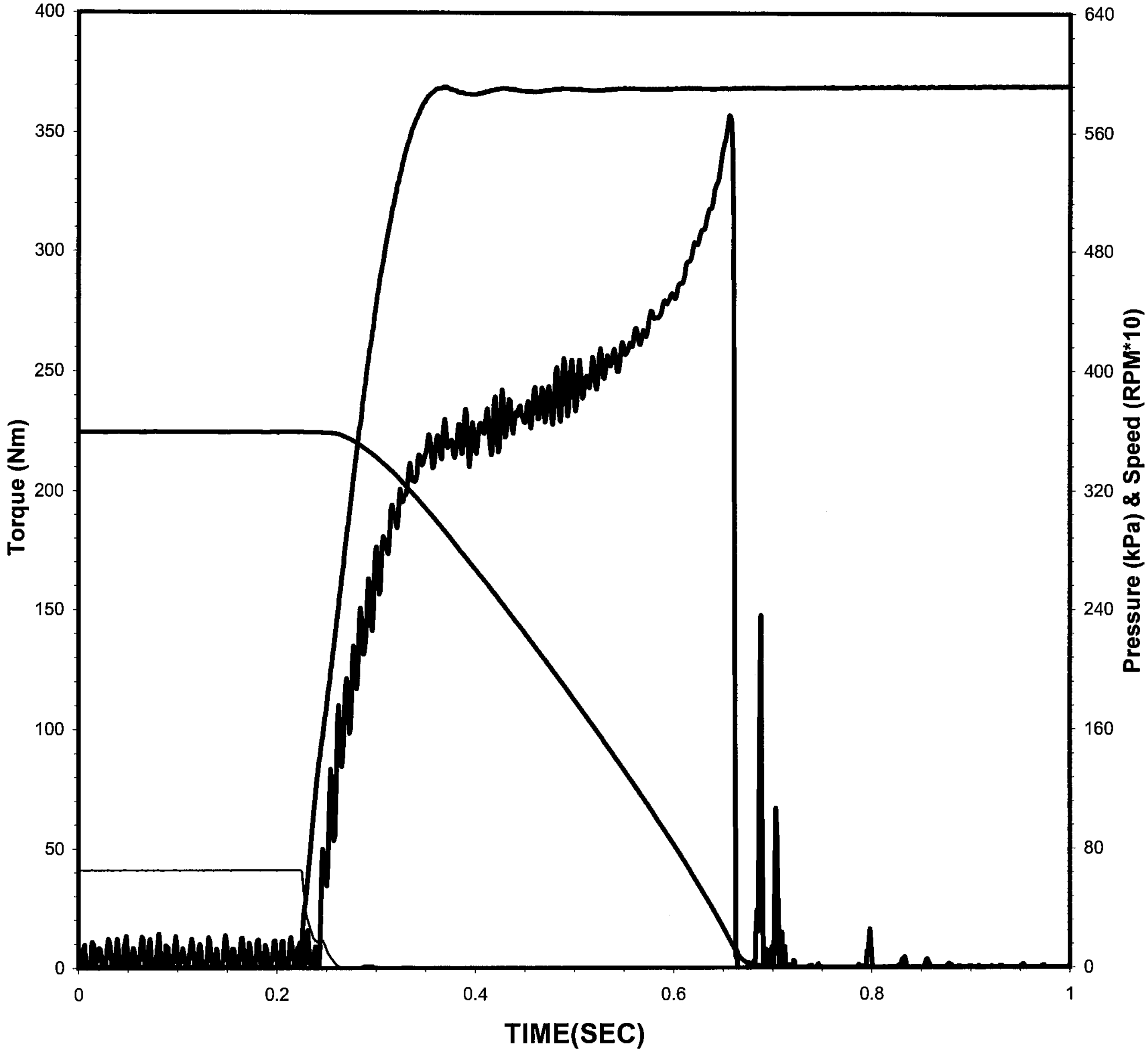
0.2 Sec Dyn:	221 N*m
Midpoint Dyn:	224 N*m
LwSpd Dynamic:	359 N*m

Coefficient of Friction

.2 Sec Dyn:	0.107
Midpoint Dyn:	0.109
LwSpd Dynamic:	0.175

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/21/2010
Time of Test:	12:30:07
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	999
Temperature:	93.0 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	588 kPa
	(586 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.6 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.44 Sec

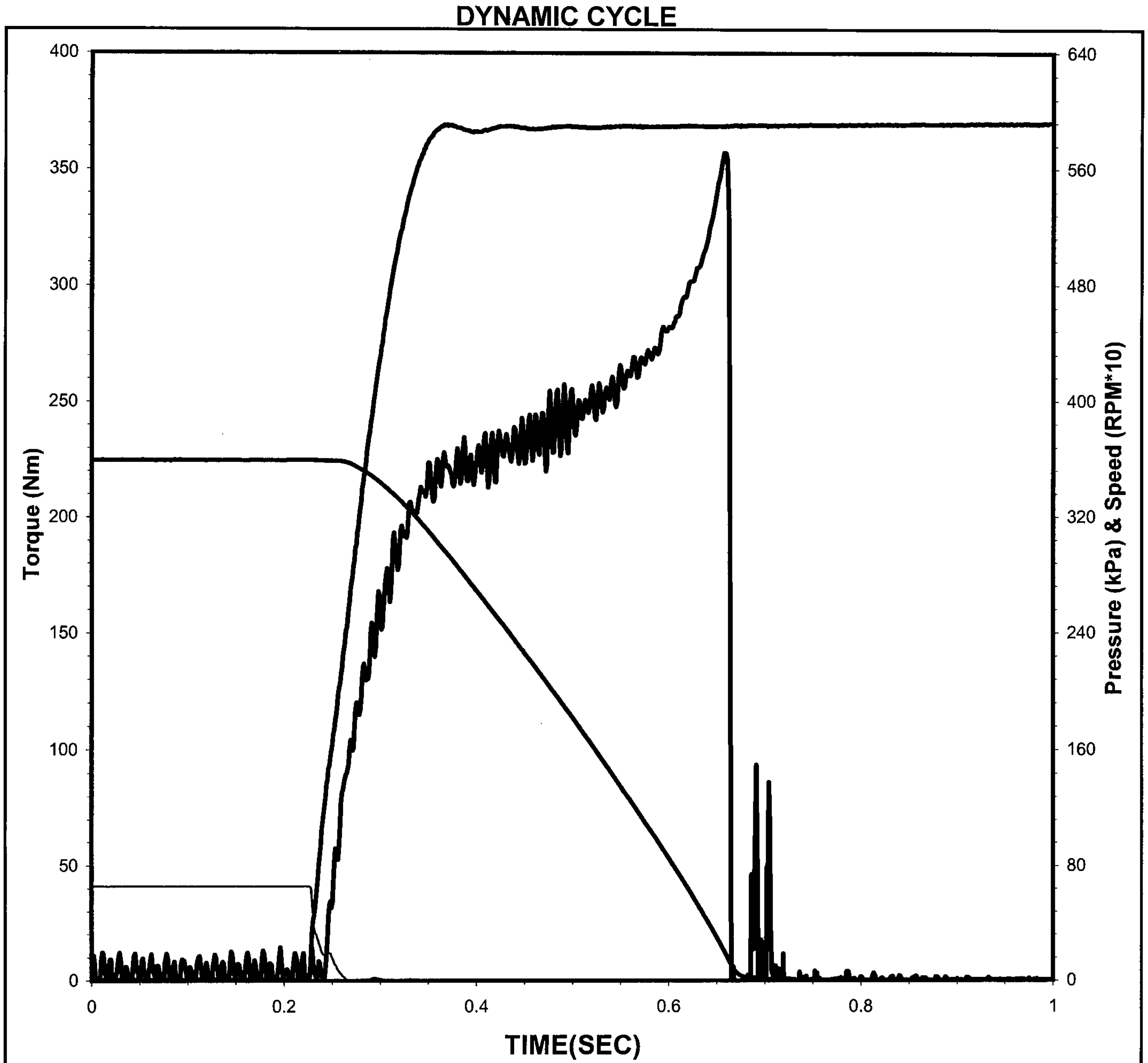
Torque

0.2 Sec Dyn:	230 N*m
Midpoint Dyn:	232 N*m
LwSpd Dynamic:	354 N*m

Coefficient of Friction

.2 Sec Dyn:	0.112
Midpoint Dyn:	0.113
LwSpd Dynamic:	0.173

ALLISON C-4 PAPER DATA



Date of Test:	7/21/2010
Time of Test:	12:30:22
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	1000
Temperature:	92.9 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.437 Sec

Torque

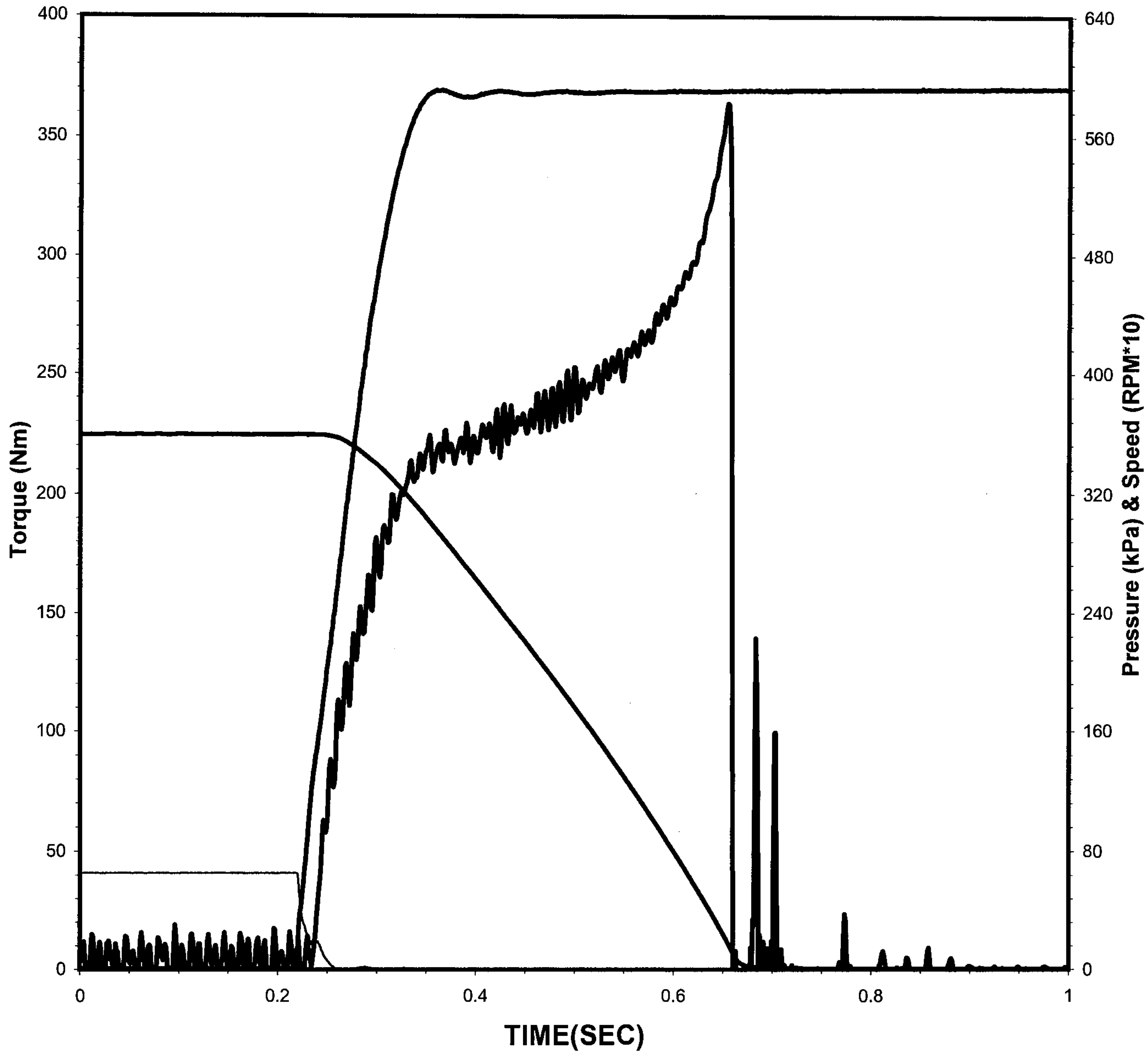
0.2 Sec Dyn:	230 N*m
Midpoint Dyn:	233 N*m
LwSpd Dynamic:	347 N*m

Coefficient of Friction

.2 Sec Dyn:	0.112
Midpoint Dyn:	0.113
LwSpd Dynamic:	0.169

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/21/2010
Time of Test:	12:30:53
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	1001
Temperature:	87.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	588 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.44 Sec

Torque

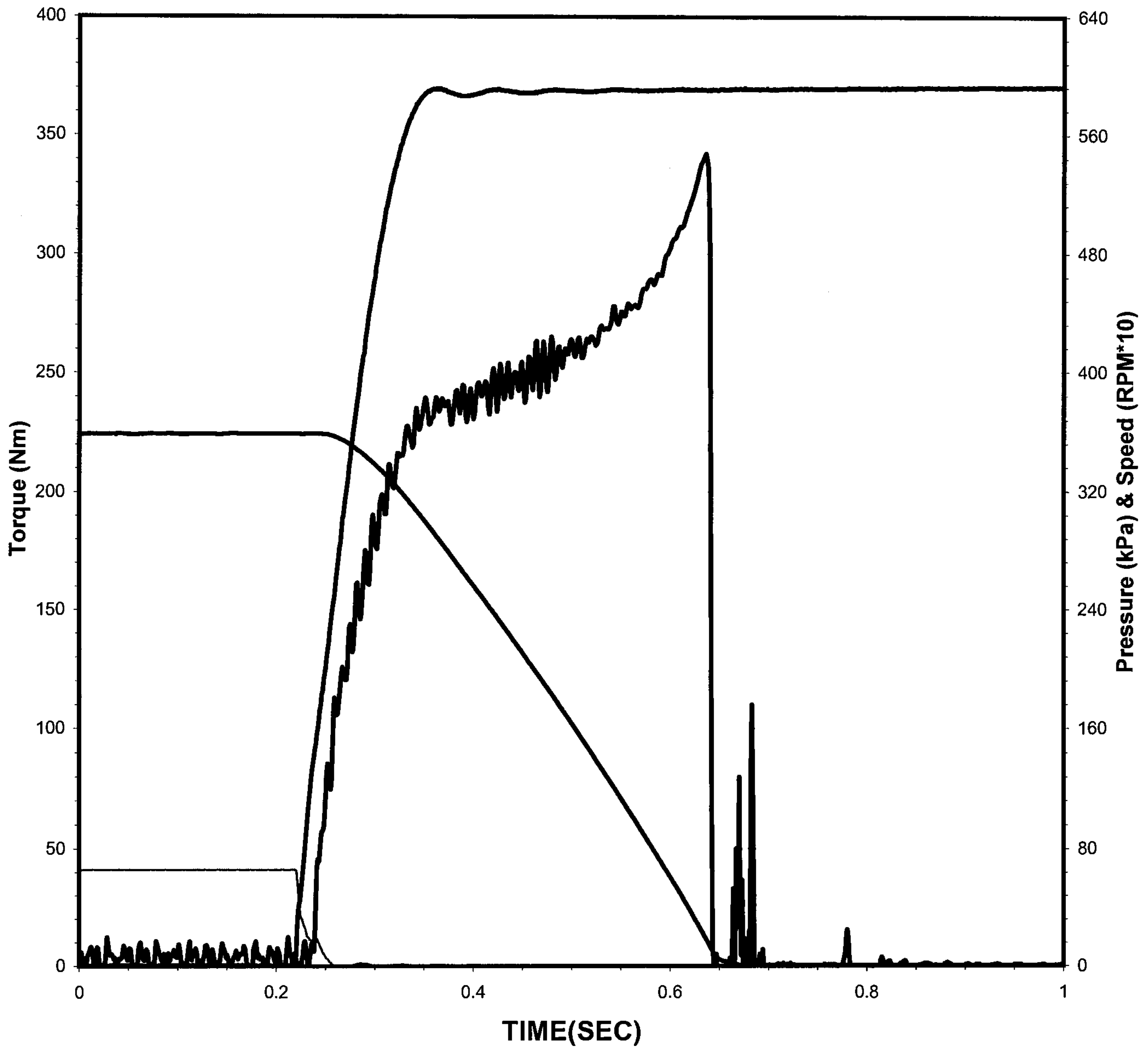
0.2 Sec Dyn:	226 N*m
Midpoint Dyn:	229 N*m
LwSpd Dynamic:	359 N*m

Coefficient of Friction

.2 Sec Dyn:	0.110
Midpoint Dyn:	0.111
LwSpd Dynamic:	0.175

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/21/2010
Time of Test:	18:45:23
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	2499
Temperature:	93.0 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.424 Sec

Torque

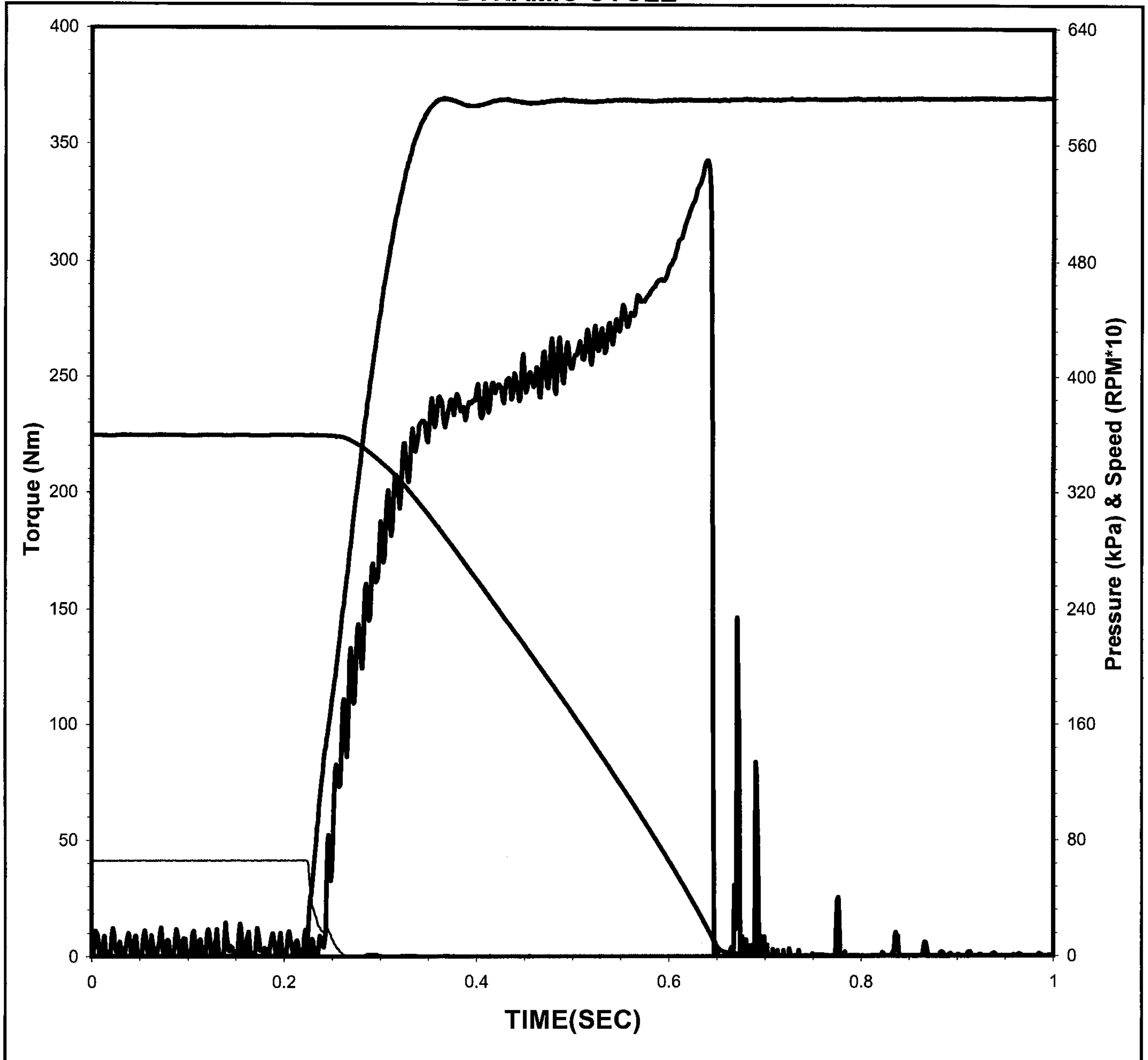
0.2 Sec Dyn:	243 N*m
Midpoint Dyn:	244 N*m
LwSpd Dynamic:	336 N*m

Coefficient of Friction

.2 Sec Dyn:	0.118
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.164

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/21/2010

Time of Test: 18:45:39

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 2500

Temperature: 92.9 °C
(93.3 ± 3.0 °C)

Apply Pressure: 589 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.7 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.422 Sec

Torque

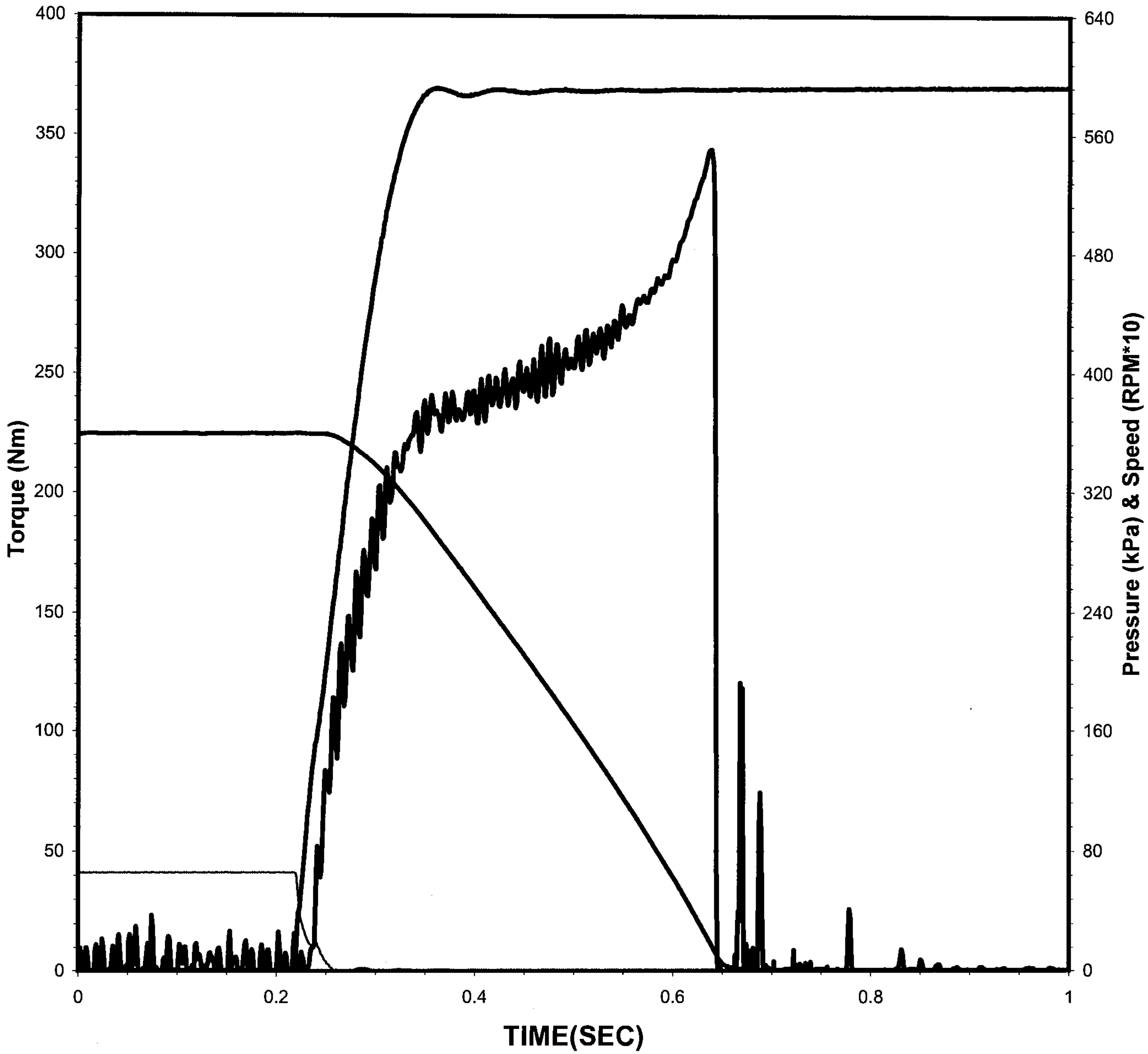
0.2 Sec Dyn:	245 N*m
Midpoint Dyn:	245 N*m
LwSpd Dynamic:	331 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.119
LwSpd Dynamic:	0.161

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/21/2010
Time of Test:	18:46:10
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	2501
Temperature:	87.4 °C (93.3 ± 3.0 °C)
Apply Pressure:	589 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.425 Sec

Torque

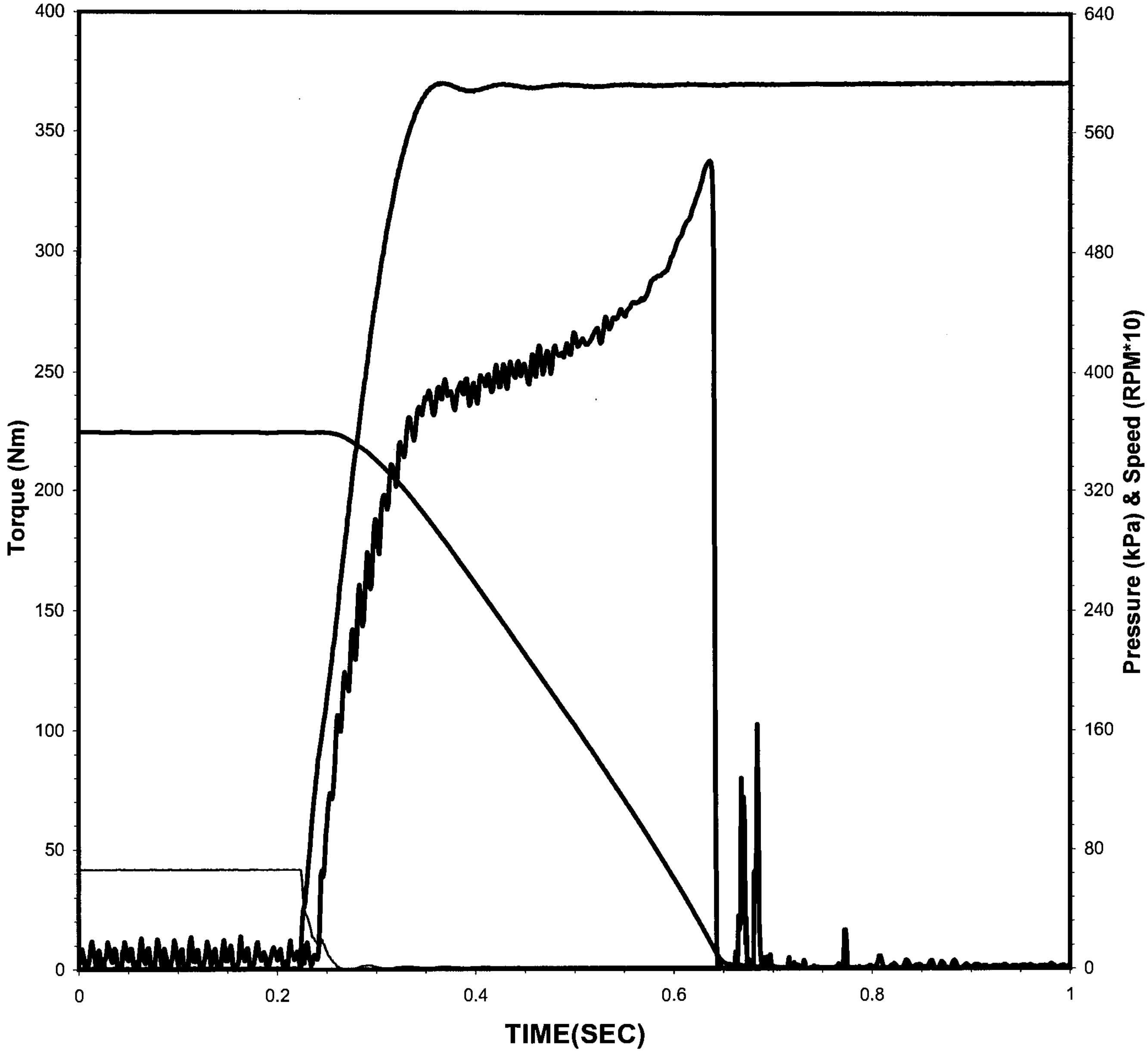
0.2 Sec Dyn:	242 N*m
Midpoint Dyn:	243 N*m
LwSpd Dynamic:	338 N*m

Coefficient of Friction

.2 Sec Dyn:	0.118
Midpoint Dyn:	0.118
LwSpd Dynamic:	0.165

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/22/2010

Time of Test: 5:10:40

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 4999

Temperature: 93.3 °C
(93.3 ± 3.0 °C)

Apply Pressure: 590 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.42 Sec

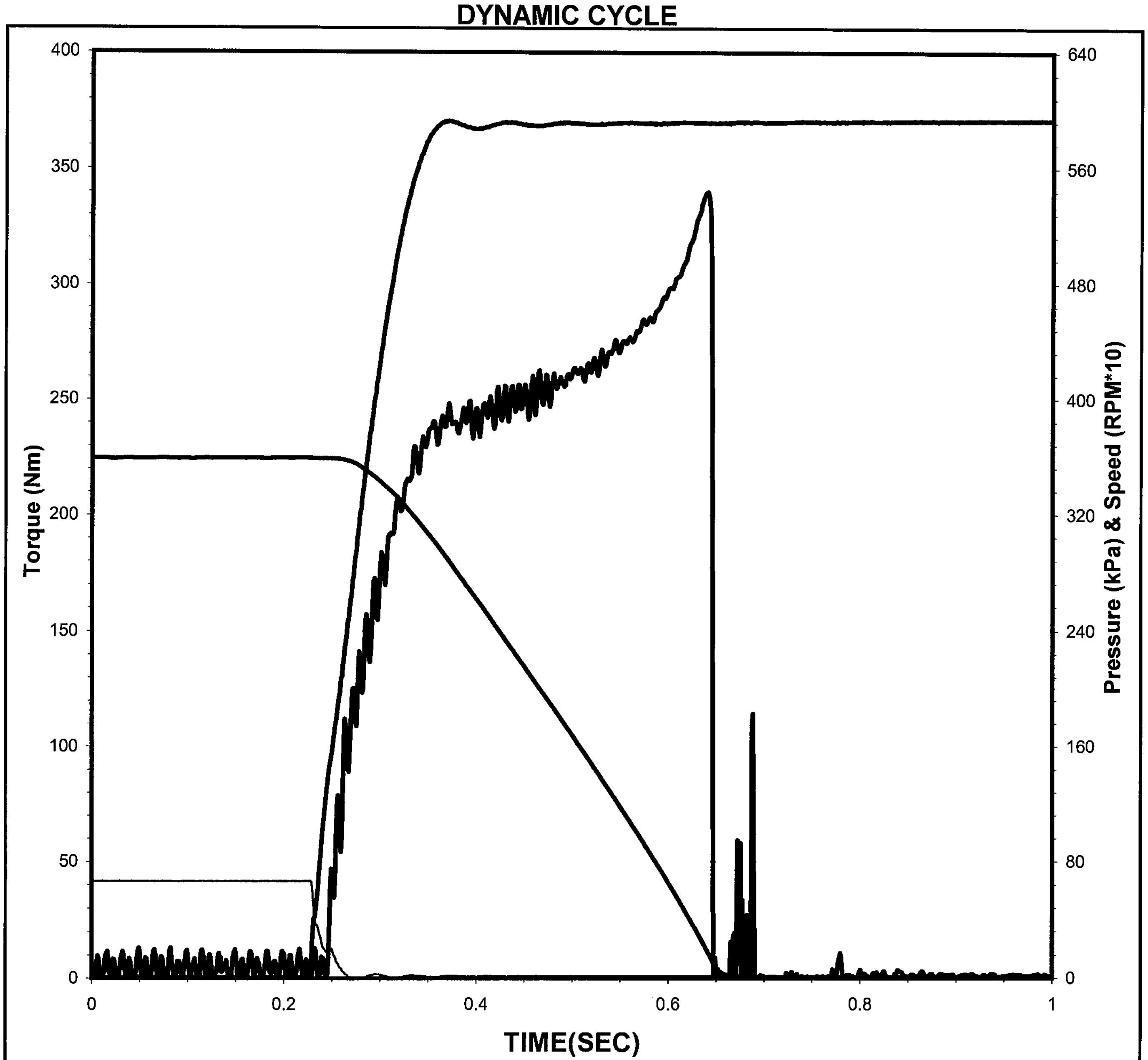
Torque

0.2 Sec Dyn:	246 N*m
Midpoint Dyn:	247 N*m
LwSpd Dynamic:	333 N*m

Coefficient of Friction

.2 Sec Dyn:	0.120
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.162

ALLISON C-4 PAPER DATA



Date of Test:	7/22/2010
Time of Test:	5:10:55
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	5000
Temperature:	92.8 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.418 Sec

Torque

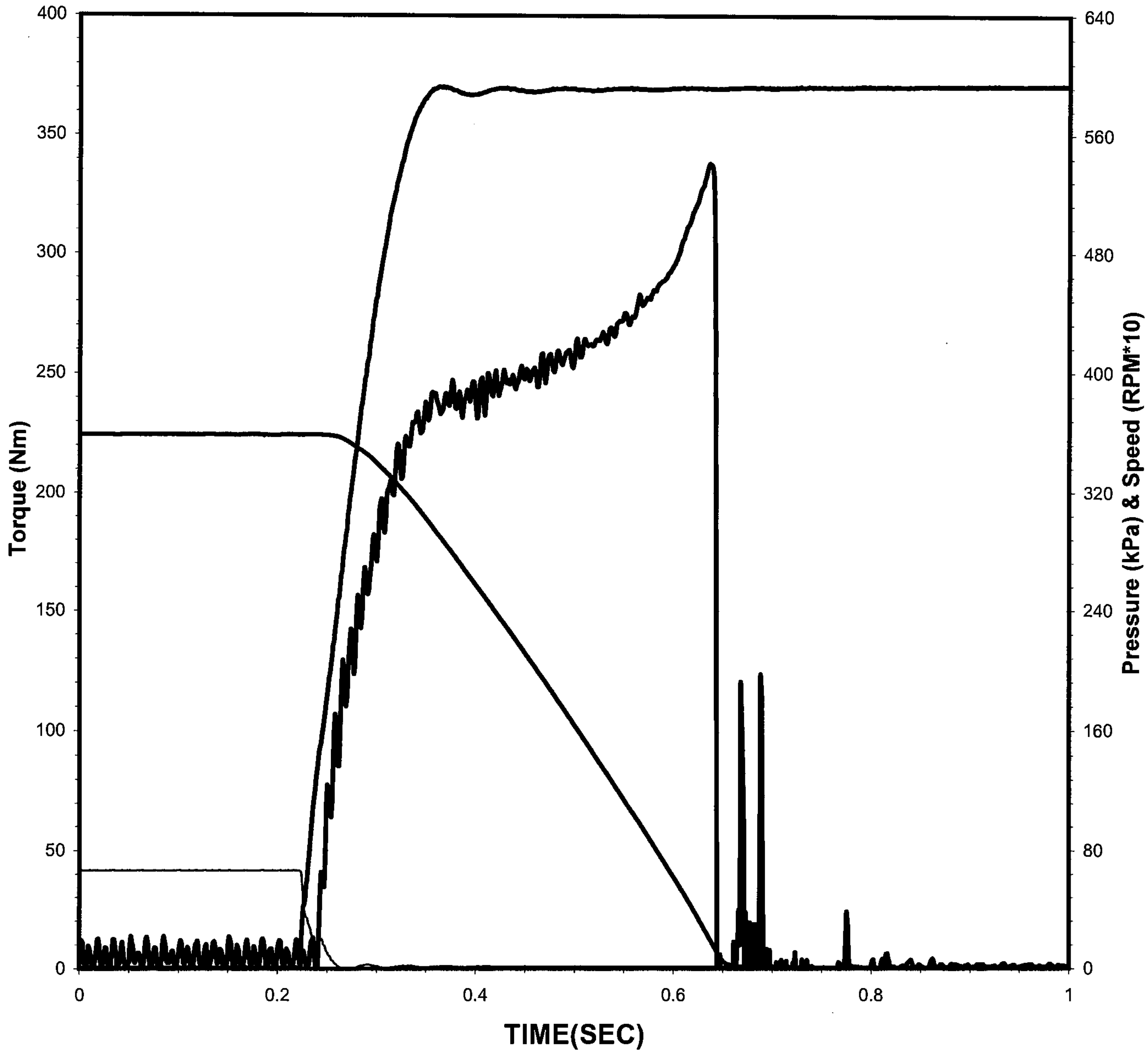
0.2 Sec Dyn:	248 N*m
Midpoint Dyn:	248 N*m
LwSpd Dynamic:	329 N*m

Coefficient of Friction

.2 Sec Dyn:	0.121
Midpoint Dyn:	0.121
LwSpd Dynamic:	0.160

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/22/2010
Time of Test:	5:11:26
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	5001
Temperature:	87.0 °C
	(93.3 ± 3.0 °C)
Apply Pressure:	590 kPa
	(586 ± 7 KPa)
Apply Rate:	0.13 Sec
	(0.15 ± 0.02 Sec)
Energy:	18.6 KJ
	(18.7 ± 0.40 KJ)
Engage Time:	0.42 Sec

Torque

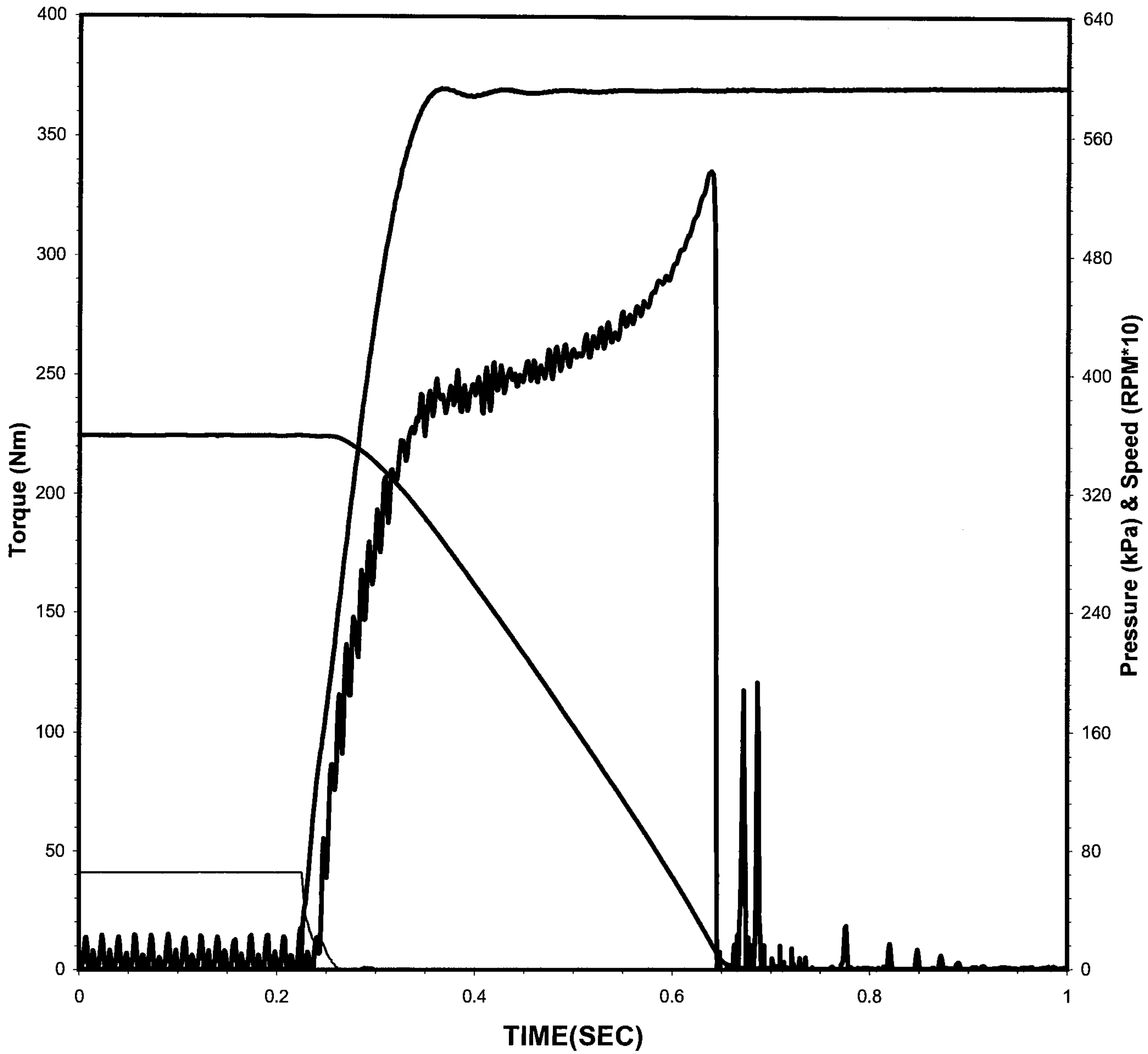
0.2 Sec Dyn:	245 N*m
Midpoint Dyn:	245 N*m
LwSpd Dynamic:	331 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.161

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/22/2010**
Time of Test:	**15:35:56**
Test Number:	**C2-6-1551**
Fluid Code:	**LO-251746**
Cycle Number:	**7499**
Temperature:	**92.6 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**590 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.7 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.421 Sec**

Torque

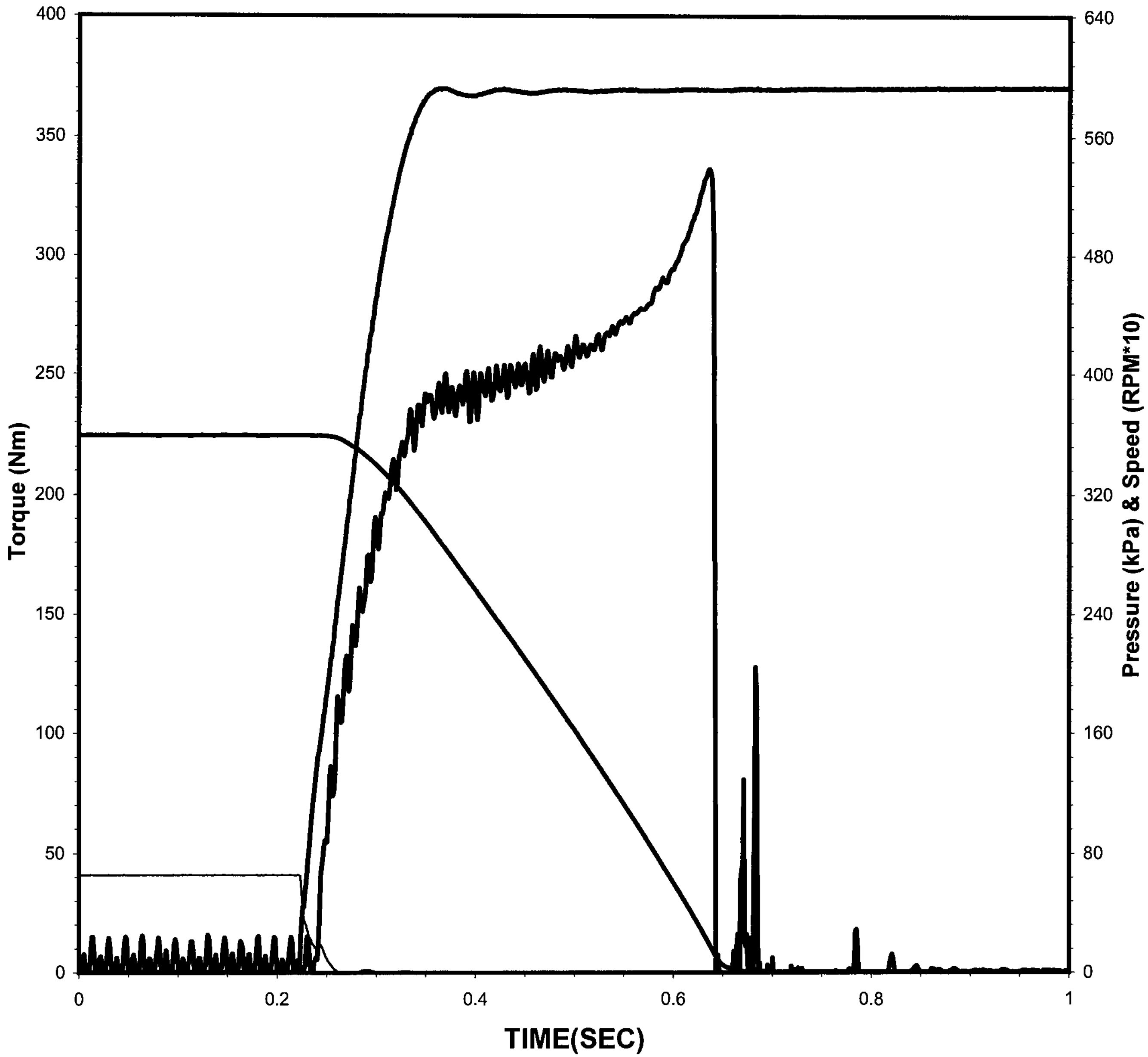
0.2 Sec Dyn:	**248 N*m**
Midpoint Dyn:	**248 N*m**
LwSpd Dynamic:	**329 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.121**
Midpoint Dyn:	**0.121**
LwSpd Dynamic:	**0.160**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	7/22/2010
Time of Test:	15:36:11
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	7500
Temperature:	92.6 °C (93.3 ± 3.0 °C)
Apply Pressure:	590 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.6 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.42 Sec

Torque

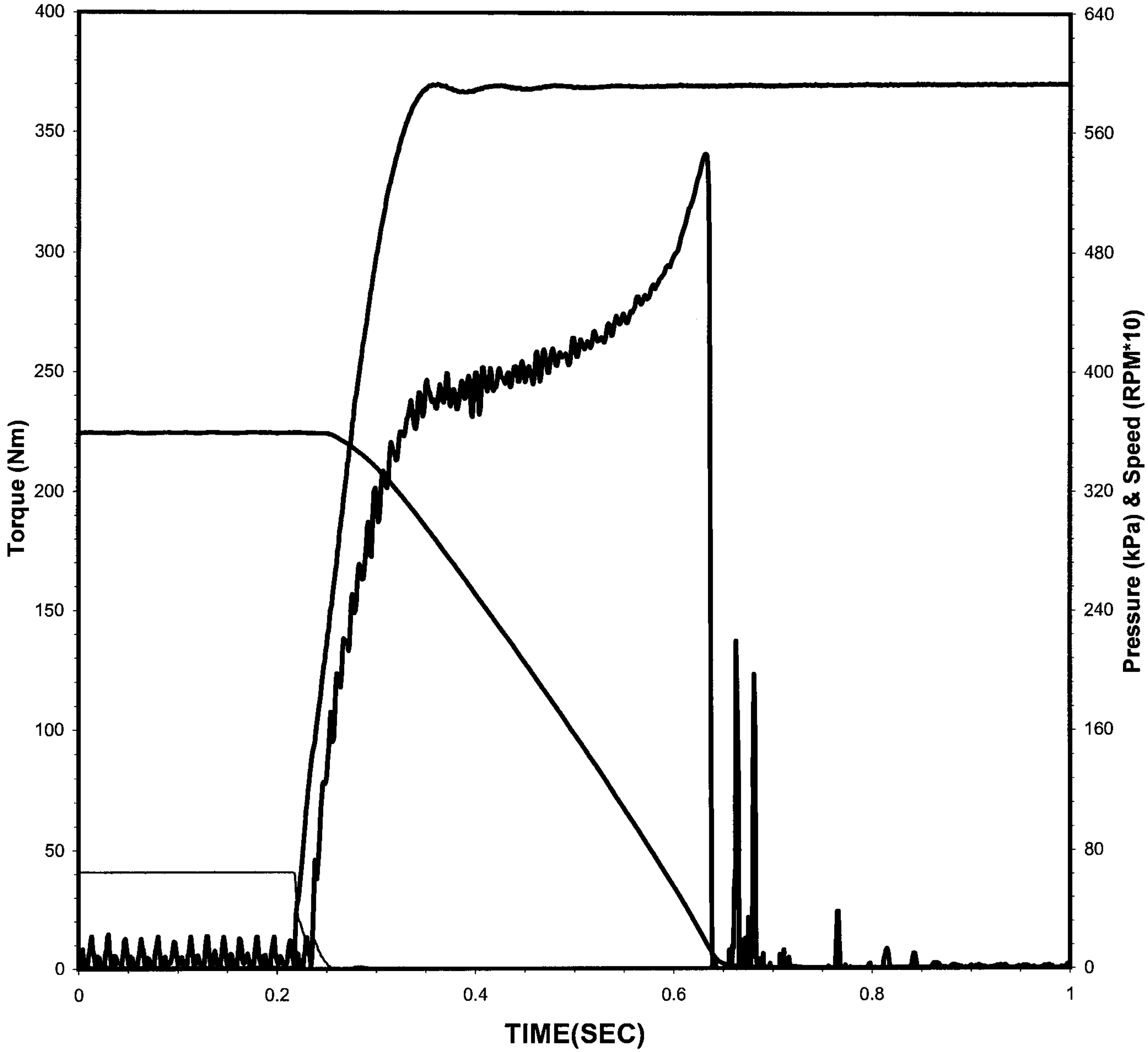
0.2 Sec Dyn:	245 N*m
Midpoint Dyn:	246 N*m
LwSpd Dynamic:	327 N*m

Coefficient of Friction

.2 Sec Dyn:	0.119
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.159

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/22/2010**
Time of Test:	**15:36:42**
Test Number:	**C2-6-1551**
Fluid Code:	**LO-251746**
Cycle Number:	**7501**
Temperature:	**88.0 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**590 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.7 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.421 Sec**

Torque

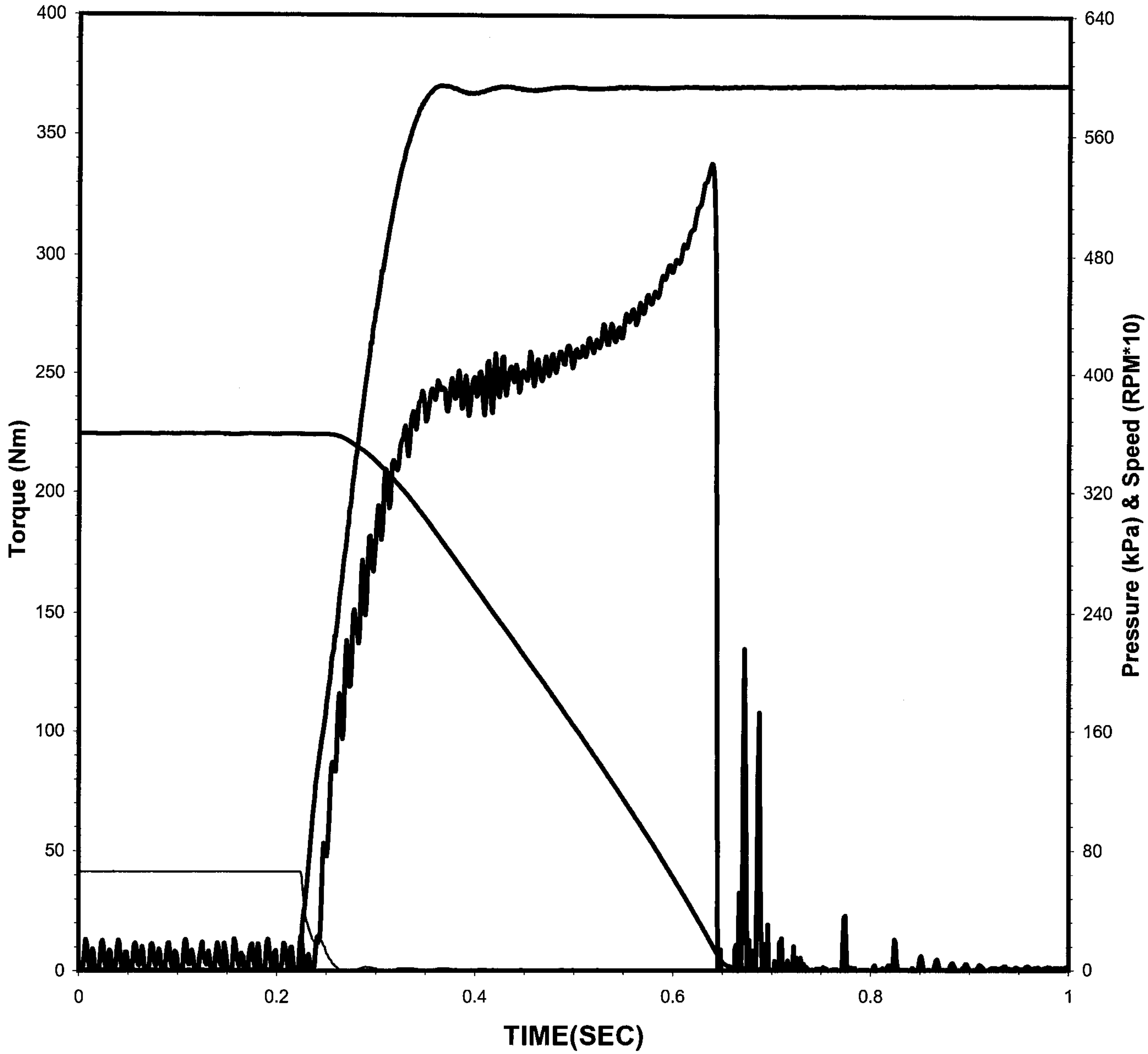
0.2 Sec Dyn:	**246 N*m**
Midpoint Dyn:	**246 N*m**
LwSpd Dynamic:	**336 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.120**
Midpoint Dyn:	**0.120**
LwSpd Dynamic:	**0.164**

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test:	**7/23/2010**
Time of Test:	**2:00:57**
Test Number:	**C2-6-1551**
Fluid Code:	**LO-251746**
Cycle Number:	**9998**
Temperature:	**93.0 °C** (93.3 ± 3.0 °C)
Apply Pressure:	**591 kPa** (586 ± 7 KPa)
Apply Rate:	**0.13 Sec** (0.15 ± 0.02 Sec)
Energy:	**18.7 KJ** (18.7 ± 0.40 KJ)
Engage Time:	**0.421 Sec**

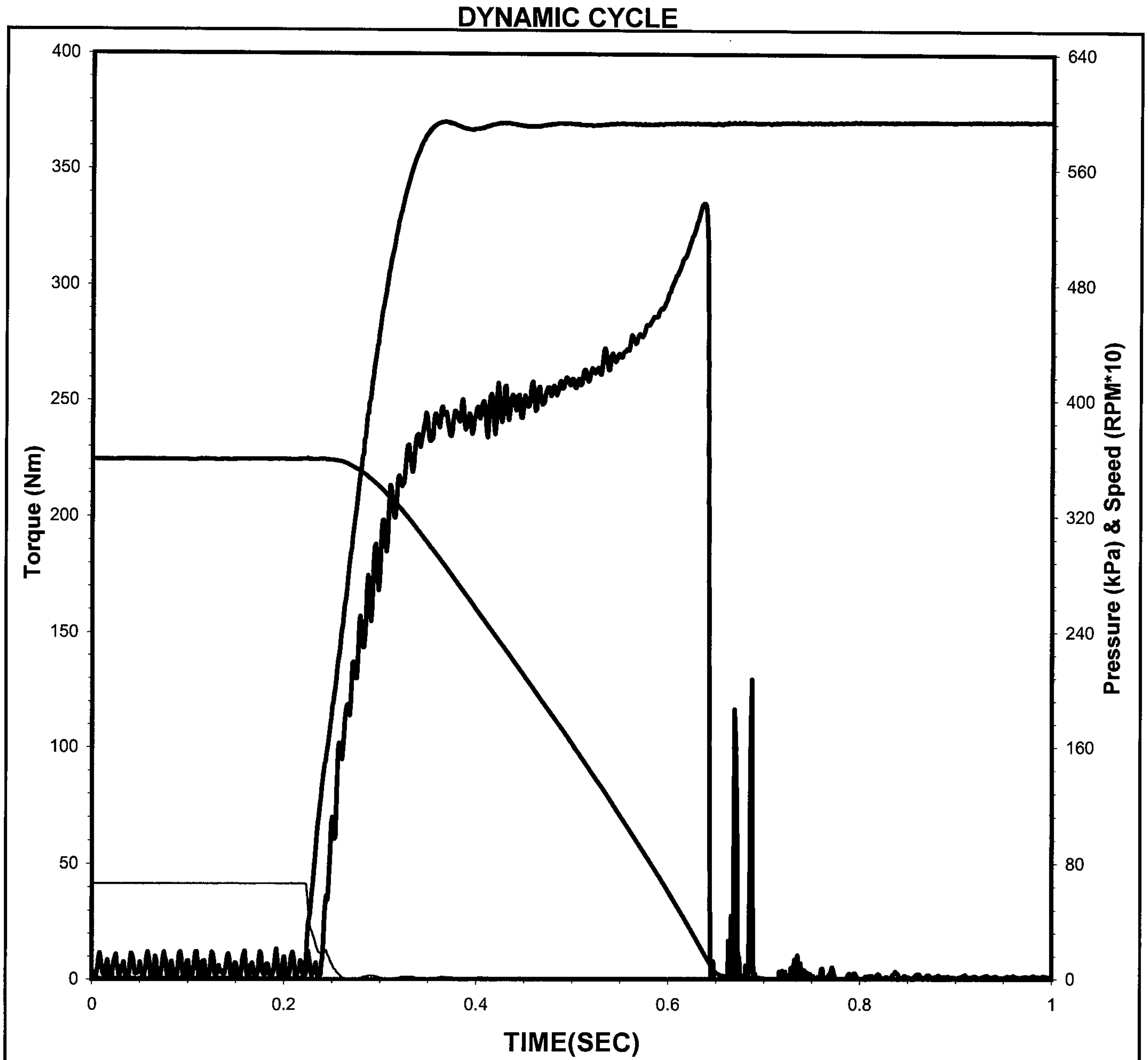
Torque

0.2 Sec Dyn:	**247 N*m**
Midpoint Dyn:	**248 N*m**
LwSpd Dynamic:	**327 N*m**

Coefficient of Friction

.2 Sec Dyn:	**0.120**
Midpoint Dyn:	**0.121**
LwSpd Dynamic:	**0.159**

ALLISON C-4 PAPER DATA



Date of Test:	7/23/2010
Time of Test:	2:01:12
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	9999
Temperature:	93.1 °C (93.3 ± 3.0 °C)
Apply Pressure:	591 kPa (586 ± 7 KPa)
Apply Rate:	0.13 Sec (0.15 ± 0.02 Sec)
Energy:	18.7 KJ (18.7 ± 0.40 KJ)
Engage Time:	0.422 Sec

Torque

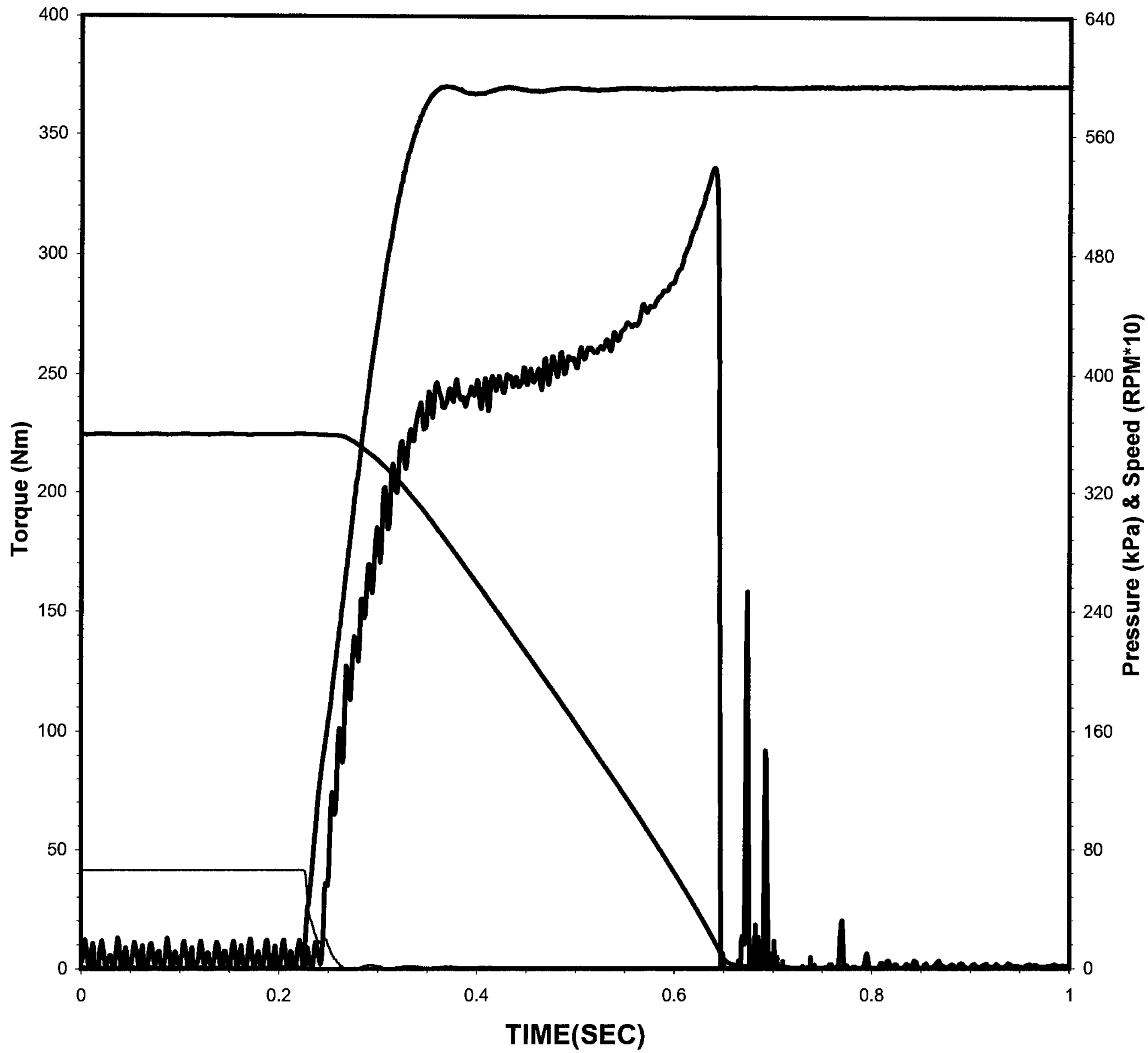
0.2 Sec Dyn:	246 N*m
Midpoint Dyn:	246 N*m
LwSpd Dynamic:	330 N*m

Coefficient of Friction

.2 Sec Dyn:	0.120
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.161

ALLISON C-4 PAPER DATA

DYNAMIC CYCLE



Date of Test: 7/23/2010

Time of Test: 2:01:28

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 10000

Temperature: 92.8 °C
(93.3 ± 3.0 °C)

Apply Pressure: 591 kPa
(586 ± 7 KPa)

Apply Rate: 0.13 Sec
(0.15 ± 0.02 Sec)

Energy: 18.6 KJ
(18.7 ± 0.40 KJ)

Engage Time: 0.42 Sec

Torque

0.2 Sec Dyn:	246 N*m
Midpoint Dyn:	246 N*m
LwSpd Dynamic:	326 N*m

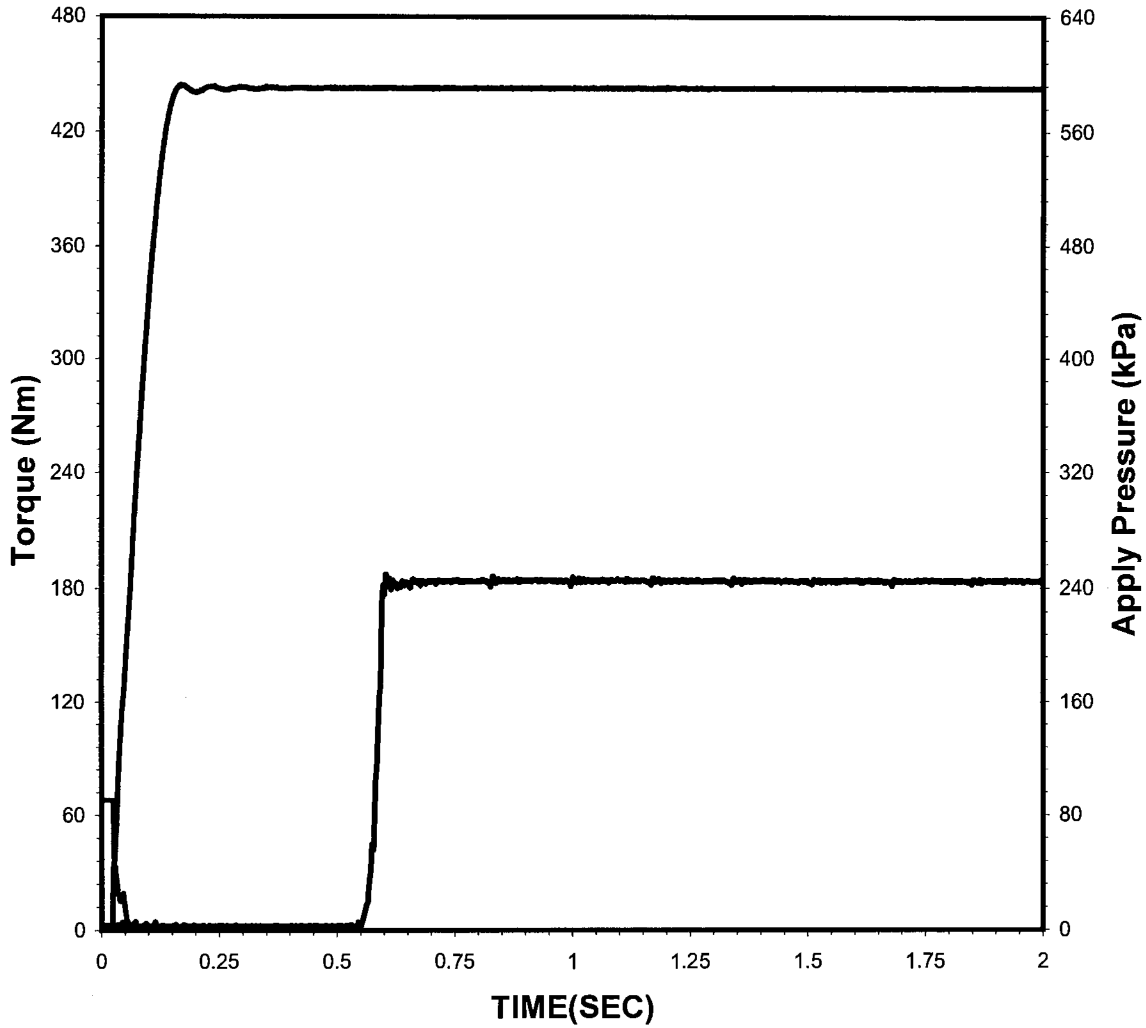
Coefficient of Friction

.2 Sec Dyn:	0.120
Midpoint Dyn:	0.120
LwSpd Dynamic:	0.159

STATIC TRACES

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 8:22:19

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 10

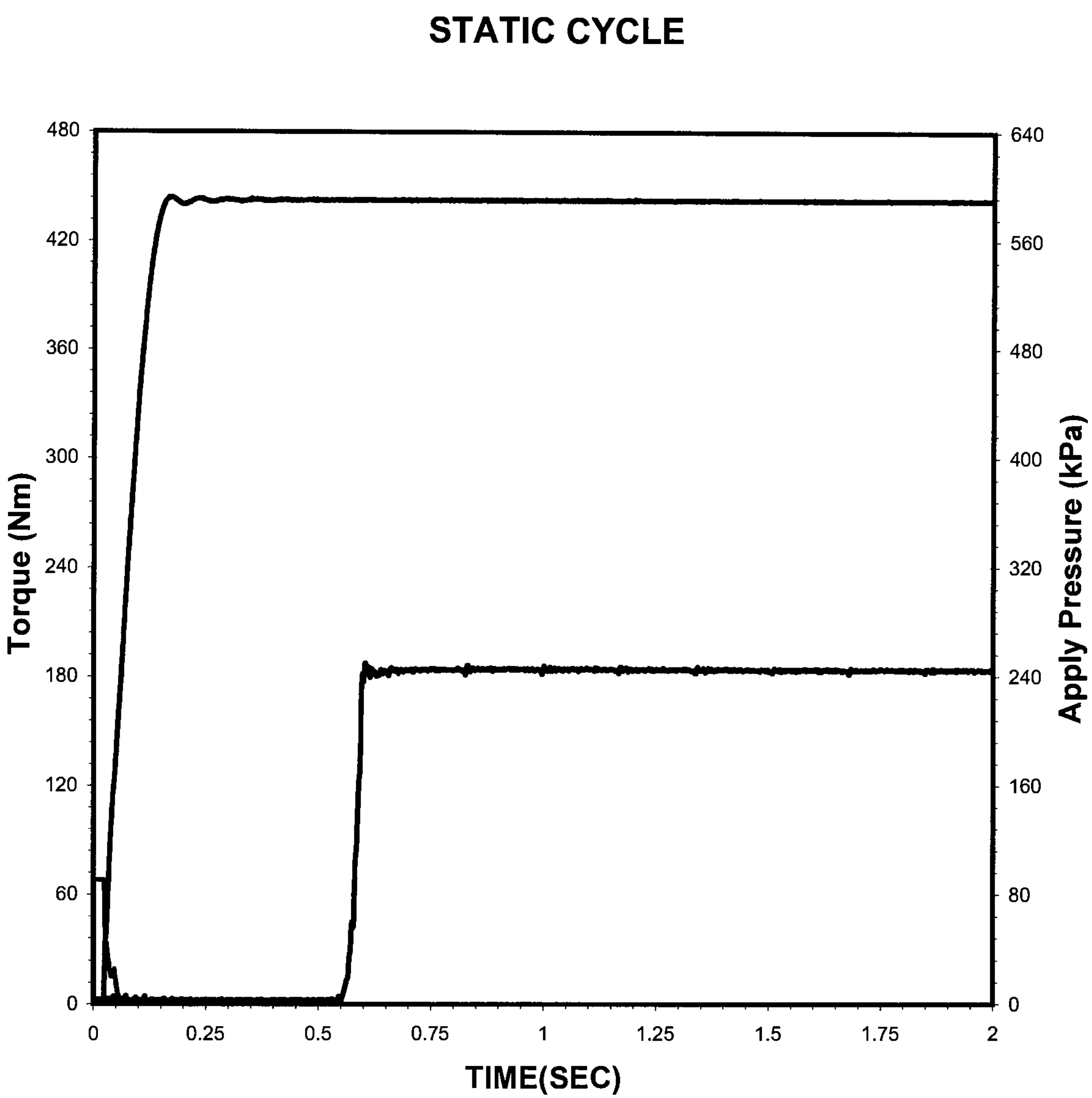
STATIC CYCLE

Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 391 Nm
.25 Second: 371 Nm

Coefficient of Friction
Static Peak: 0.191
.25 Second: 0.181

ALLISON C-4 PAPER DATA



Date of Test: 7/21/2010

Time of Test: 8:45:06

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 100

STATIC CYCLE

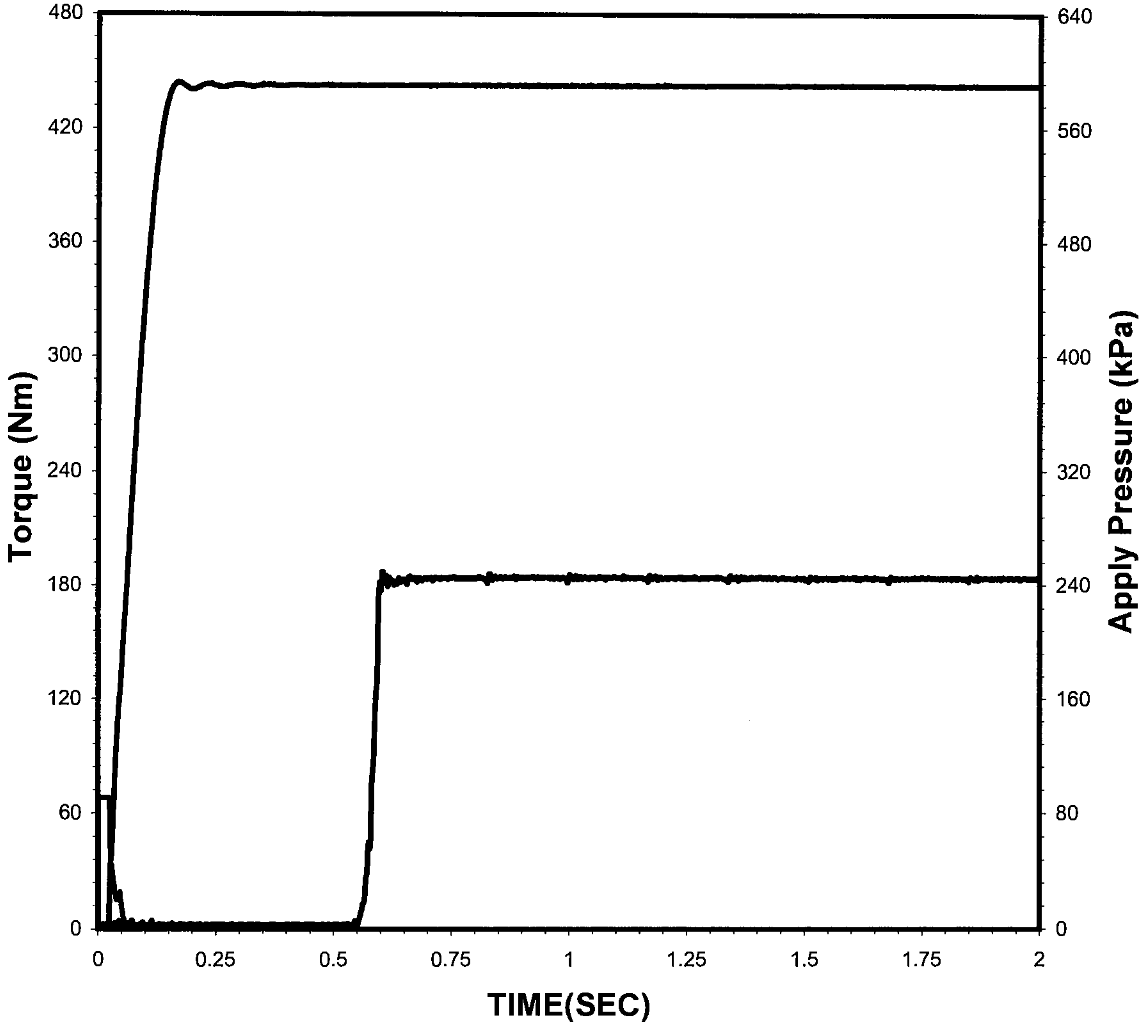
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 404 Nm
.25 Second: 374 Nm

Coefficient of Friction
Static Peak: 0.197
.25 Second: 0.182

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 10:25:22

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 500

STATIC CYCLE

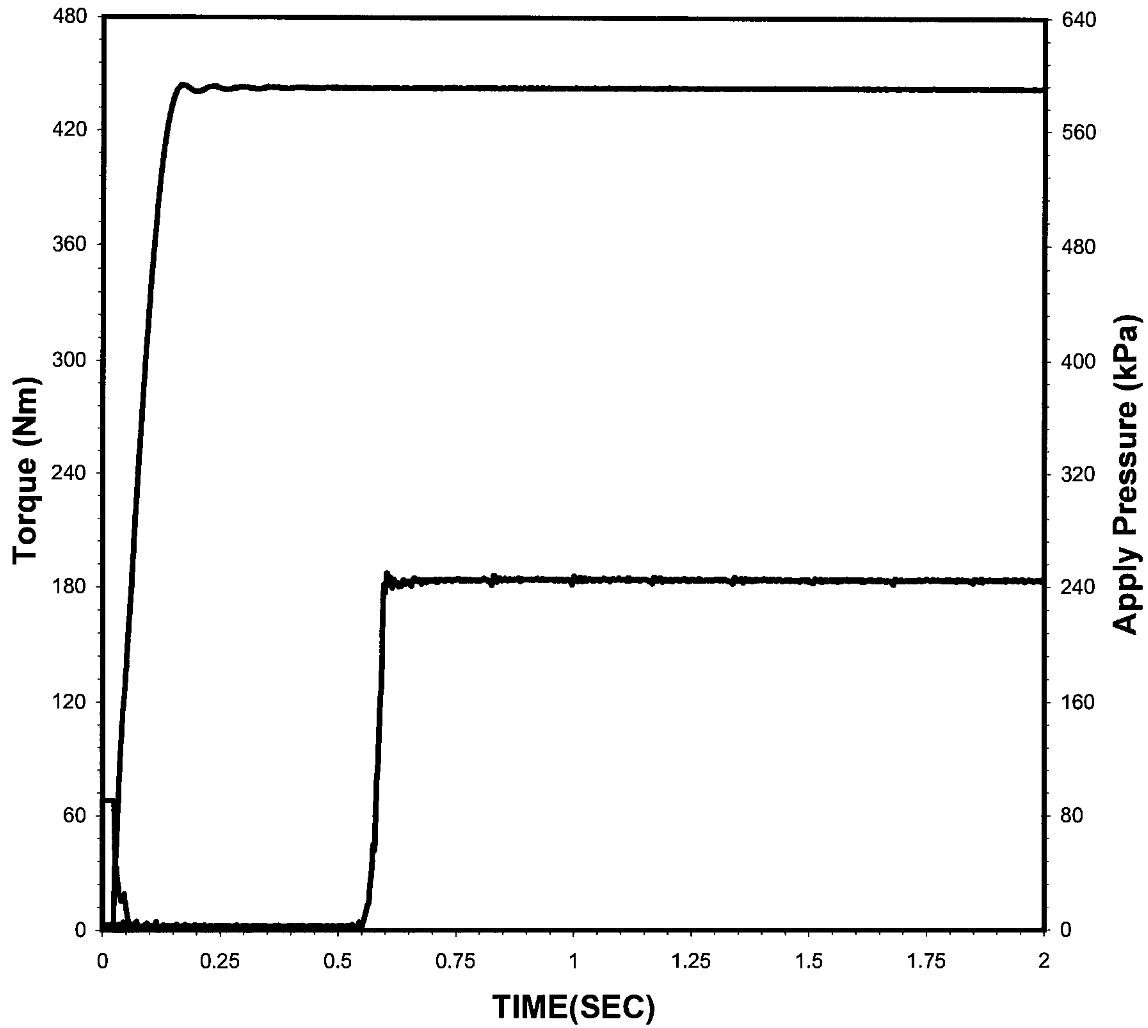
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 386 Nm
.25 Second: 376 Nm

Coefficient of Friction
Static Peak: 0.188
.25 Second: 0.183

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 12:30:38

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 1000

STATIC CYCLE

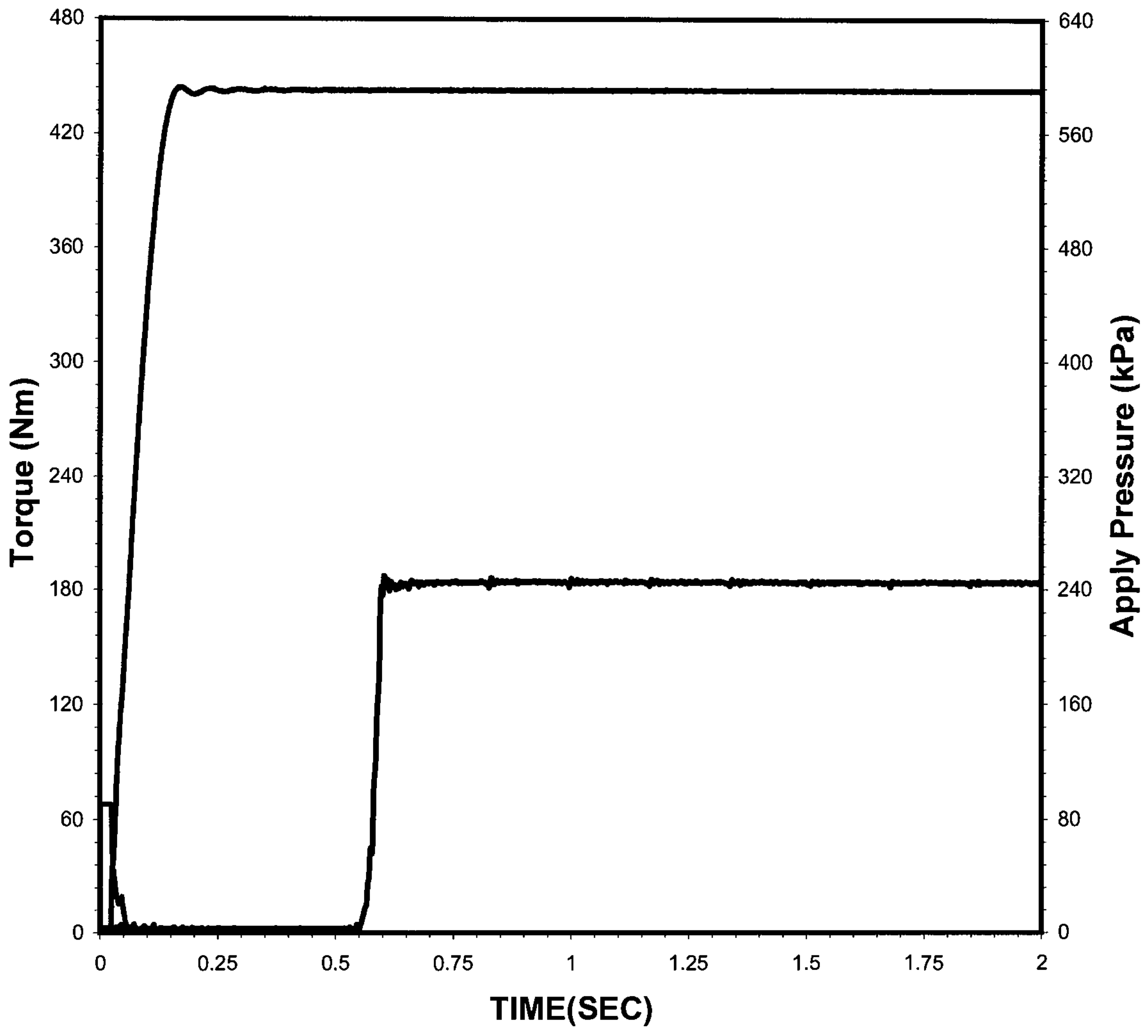
Apply Pressure:
At .25 Second: 588 kPa

Torque
Static Peak: 375 Nm
.25 Second: 365 Nm

Coefficient of Friction
Static Peak: 0.183
.25 Second: 0.178

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/21/2010

Time of Test: 18:45:55

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 2500

STATIC CYCLE

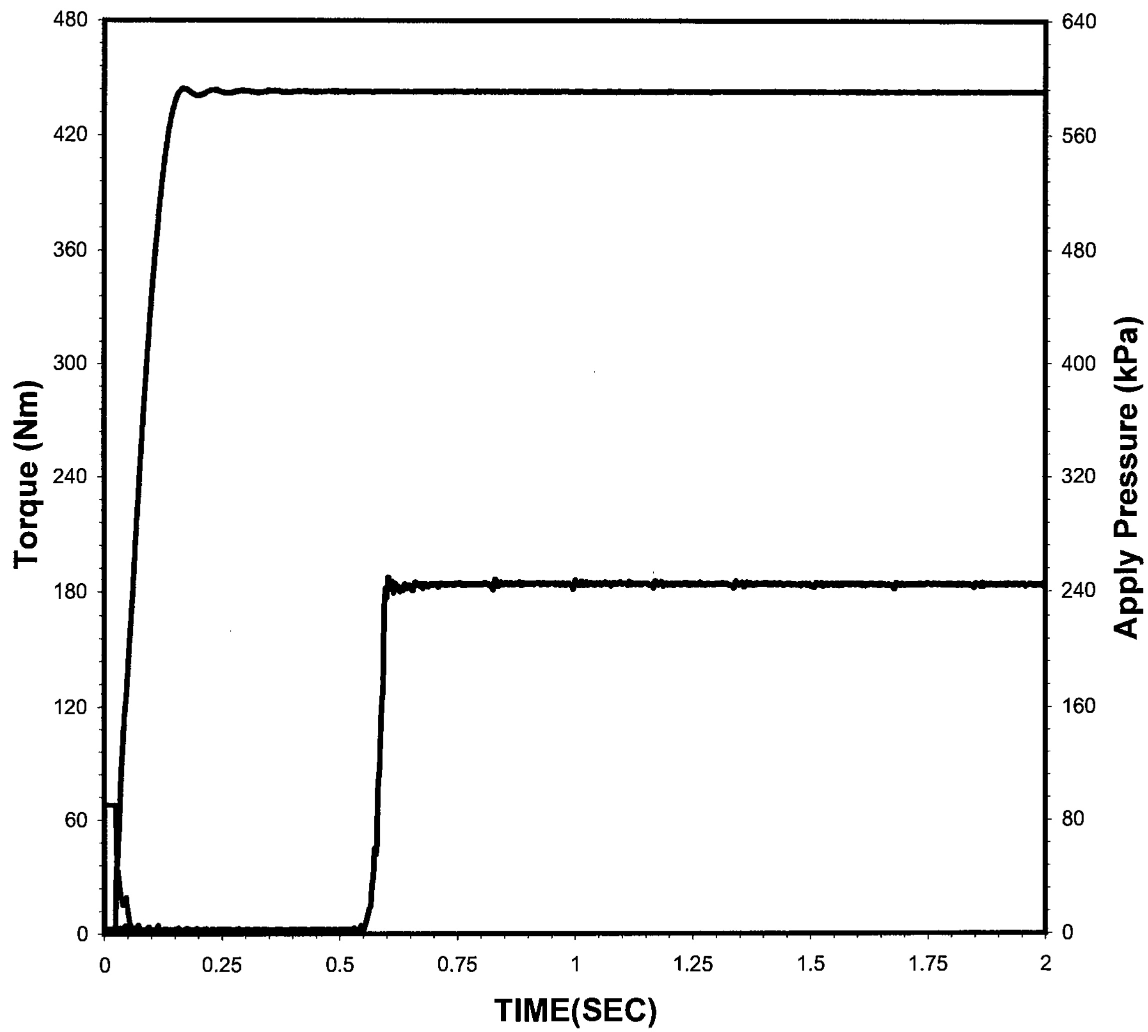
Apply Pressure:
At .25 Second: 589 kPa

Torque
Static Peak: 364 Nm
.25 Second: 349 Nm

Coefficient of Friction
Static Peak: 0.177
.25 Second: 0.170

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/22/2010

Time of Test: 5:11:11

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 5000

STATIC CYCLE

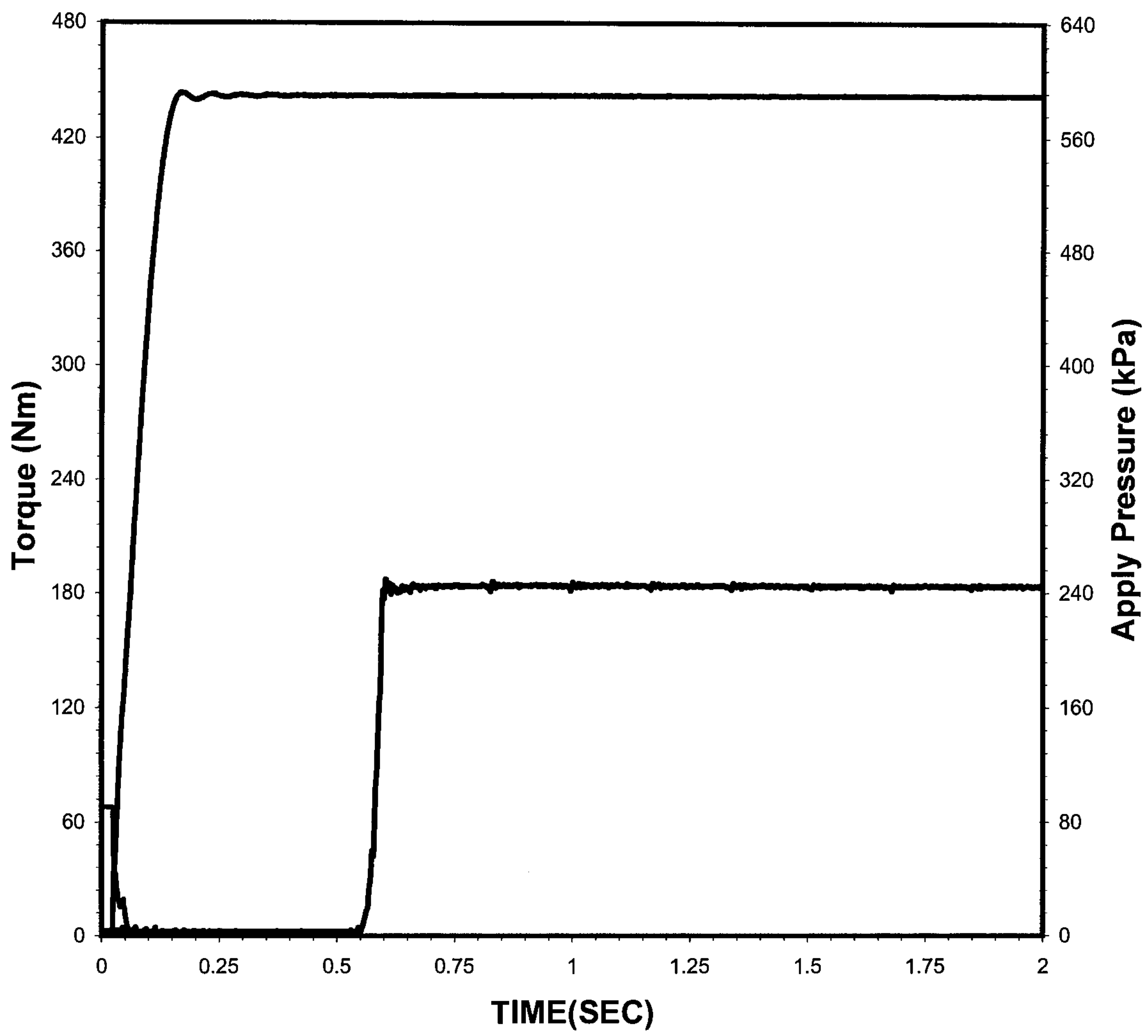
Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 348 Nm
.25 Second: 341 Nm

Coefficient of Friction
Static Peak: 0.169
.25 Second: 0.166

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test:	7/22/2010
Time of Test:	15:36:27
Test Number:	C2-6-1551
Fluid Code:	LO-251746
Cycle Number:	7500

STATIC CYCLE

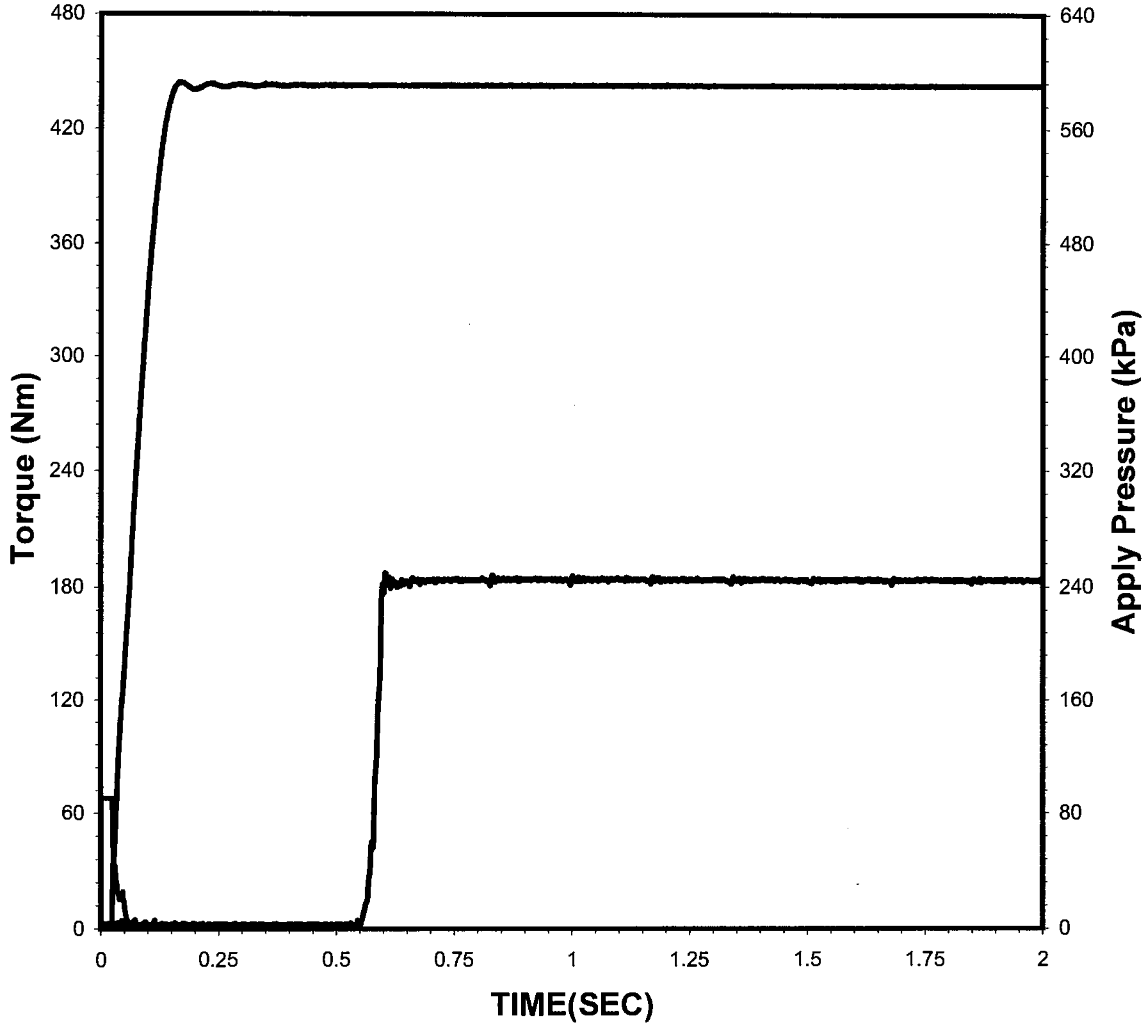
Apply Pressure:
At .25 Second: 590 kPa

Torque
Static Peak: 364 Nm
.25 Second: 341 Nm

Coefficient of Friction
Static Peak: 0.177
.25 Second: 0.166

ALLISON C-4 PAPER DATA

STATIC CYCLE



Date of Test: 7/23/2010

Time of Test: 2:01:44

Test Number: C2-6-1551

Fluid Code: LO-251746

Cycle Number: 10000

STATIC CYCLE

Apply Pressure:
At .25 Second: 591 kPa

Torque
Static Peak: 356 Nm
.25 Second: 339 Nm

Coefficient of Friction
Static Peak: 0.173
.25 Second: 0.165

C4 SEAL TEST SUMMARY SHEET

Test Sponsor: SOUTHWEST RESEARCH INSTITUTE

Oil Code: 251746
Secondary Code:
Test Key:
SwRI Code: 488555
Date: 20100810

Elastomer	Candidate			Average	MILPRF2104G Batch 12-06	Limits
V1 A-7-0060-85-ETI						
Volume Change, %	8.33	7.91	8.65	8.30	15.12	0.00 to 20.00
Hardness Change, pts.	-3	-2	-3	-3	-7	-15 to 0
V2 P-250						
Volume Change, %	5.96	4.72	5.75	5.48	8.60	0.00 to 12.00
Hardness Change, pts.	-2	-1	-1	-1	0	-7 to 3
V3 FM-L-69						
Volume Change, %	8.15	8.03	7.89	8.02	15.08	0.00 to 22.00
Hardness Change, pts.	-4	-4	-3	-4	-7	-14 to 0
P1 A-6-0160-85-ETI						
Volume Change, %	2.71	2.76	2.58	2.68	4.10	0.00 to 8.00
Hardness Change, pts.	-3	-2	-2	-2	-3	-10 to 0
P2 GR-A2256						
Volume Change, %	4.59	4.65	4.70	4.65	6.73	0.00 to 8.00
Hardness Change, pts.	-1	-1	-1	-1	-3	-11 to 3
P3 6830						
Volume Change, %	0.24	-0.03	-0.15	0.02	1.43	0.00 to 4.00
Hardness Change, pts.	0	0	0	0	-1	-8 to 4
F1 7V2127						
Volume Change, %	0.86	0.72	0.86	0.81	0.95	0.00 to 3.00
Hardness Change, pts.	0	0	0	0	0	-5 to 4
F2 V150						
Volume Change, %	1.09	1.01	1.05	1.05	1.38	0.00 to 4.00
Hardness Change, pts.	1	2	2	2	0	-2 to 5
N1 GR-N1386						
Volume Change, %	-2.97	-3.06	-3.03	-3.02	0.35	0.00 to 5.00
Hardness Change, pts.	7	8	7	7	5	-12 to 12
N2						
Volume Change, %						0.00 to 6.00
Hardness Change, pts.						-9 to 5

Rebecca D. Grinfield
Rebecca D. Grinfield
Sr. Research Scientist

APPENDIX E1. – EVALUATION OF CANDIDATE LO253071 IN CATERPILLAR TO-4 TRANSMISSION TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Conducted for

ARMY LAB

Oil Code:
LO253071

Test Numbers:
VC70-A-103-J

September 21, 2010

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluations

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: ARMY LAB

Test start date: September 14, 2010
End of test date: September 21, 2010
Oil Code: LO253071

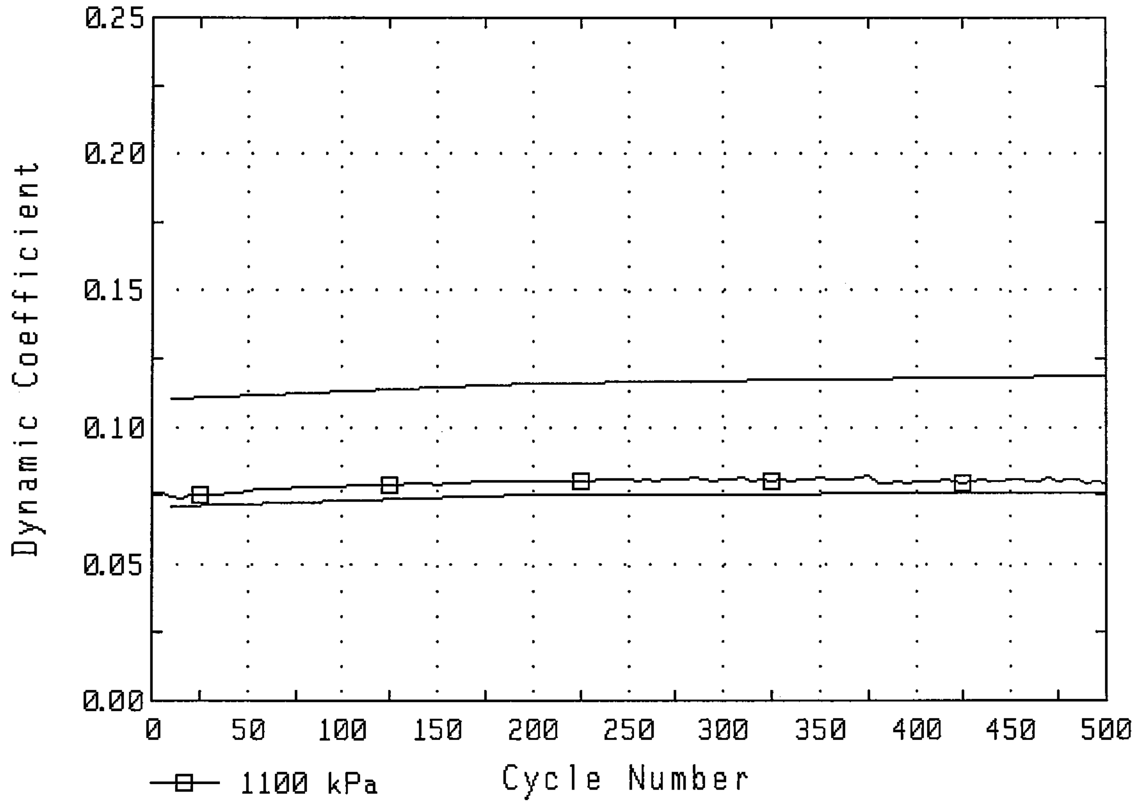
Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:		P	F				P
Dynamic Coefficient Vs. Load:		P	F				
Dynamic Coefficient Vs. Speed:		P	F				
Energy Limit:		P	P				
Static Coefficient Vs. Load:		P	F				
Static Coefficient Vs. Speed:		P	P				
Energy Limit:		P	P				
Total Wear:		0.039	0.030				
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand. The results are compared to TO-4 testing limits. 2009 Batch parts were used for all sequences except FRRET.

F = Fail
P = Pass
N/A = Not Applicable

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO253071 / LO-253071

Test name:	A-103-J
Test date:	09/14/10
Test description:	J MACHINE LO253071
Oil type:	LO253071 / LO-253071
Viscosity:	0W-30
Miscellaneous:	
Software version:	1.40
Run name & desc:	J0508217 - LO253071
Run date:	09/15/10
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J"MACHINE OIL TEST LO253071 / LO-253071
Sequence name:	SEQ1220
Remarks:	Use 1Y0709 Disc and 8E4095 Plate
Number of cycles run:	1195
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 $N\text{-}m\text{-}s^2$
Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	007080C800012
Remarks:	SINTERED BRONZE
Plate name & desc:	8E4095 - Steel Plate
Surface:	0.70 to 1.00 micron Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	007080C800012
Remarks:	0.80 SURFACE FINISH
Report limit name:	LIM1220 - Reference run: J0508081
Limit file generated:	08/04/10
Report format name:	REP1220 - SINTERED BRONZE

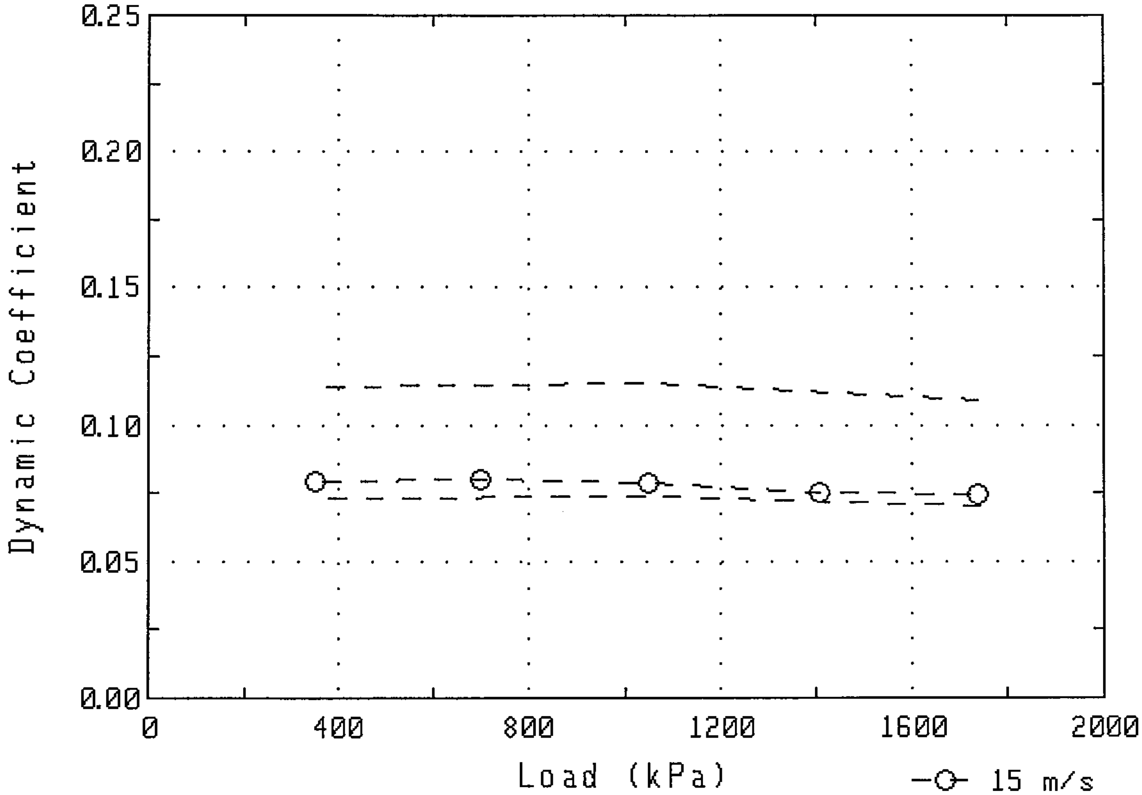


1Y0709 DISC
THICKNESS

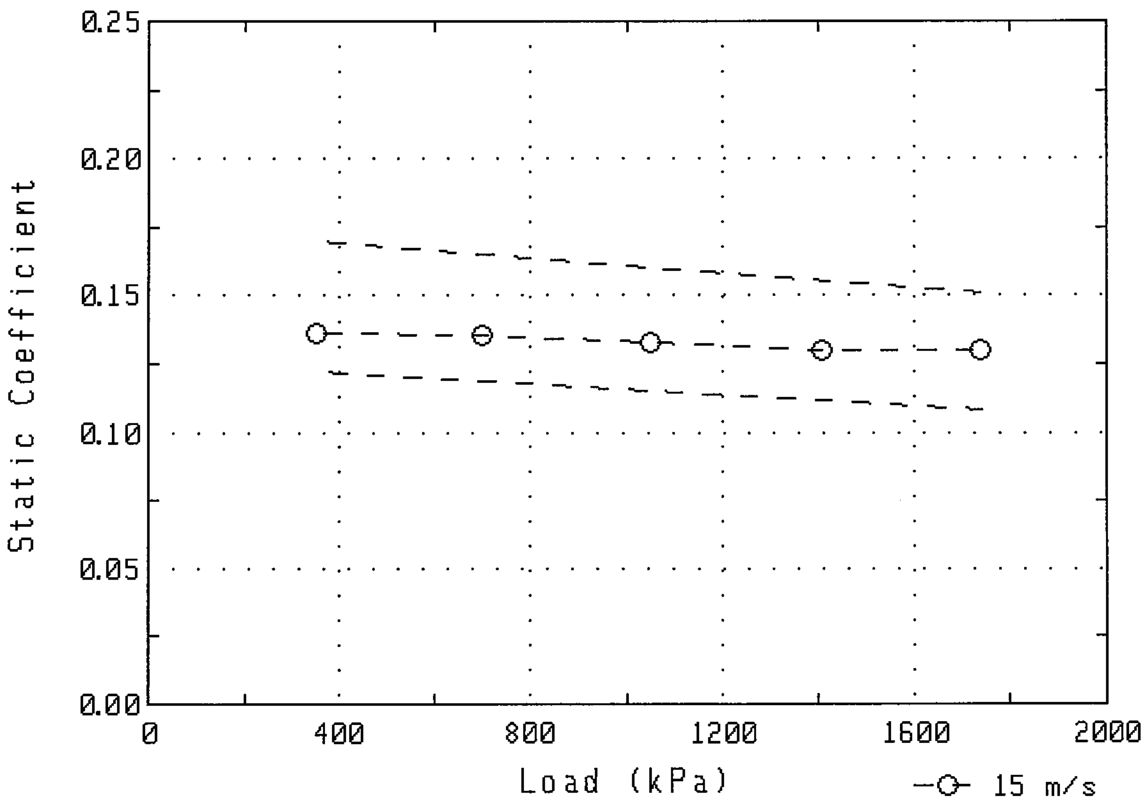
Loc	Outer Diameter M1	M2	M3	Inner Diameter M1	M2	M3
1	4.96	4.95	4.94	4.96	4.96	4.94
2	4.96	4.96	4.96	4.96	4.96	4.95
3	4.96	4.96	4.95	4.96	4.96	4.95
4	4.96	4.95	4.95	4.95	4.95	4.95
5	4.95	4.95	4.95	4.95	4.95	4.95
6	4.95	4.95	4.95	4.95	4.95	4.94
Avg	4.96	4.95	4.95	4.96	4.96	4.95

Compression set average wear: 0.002
M2 - M3 average Wear: 0.006

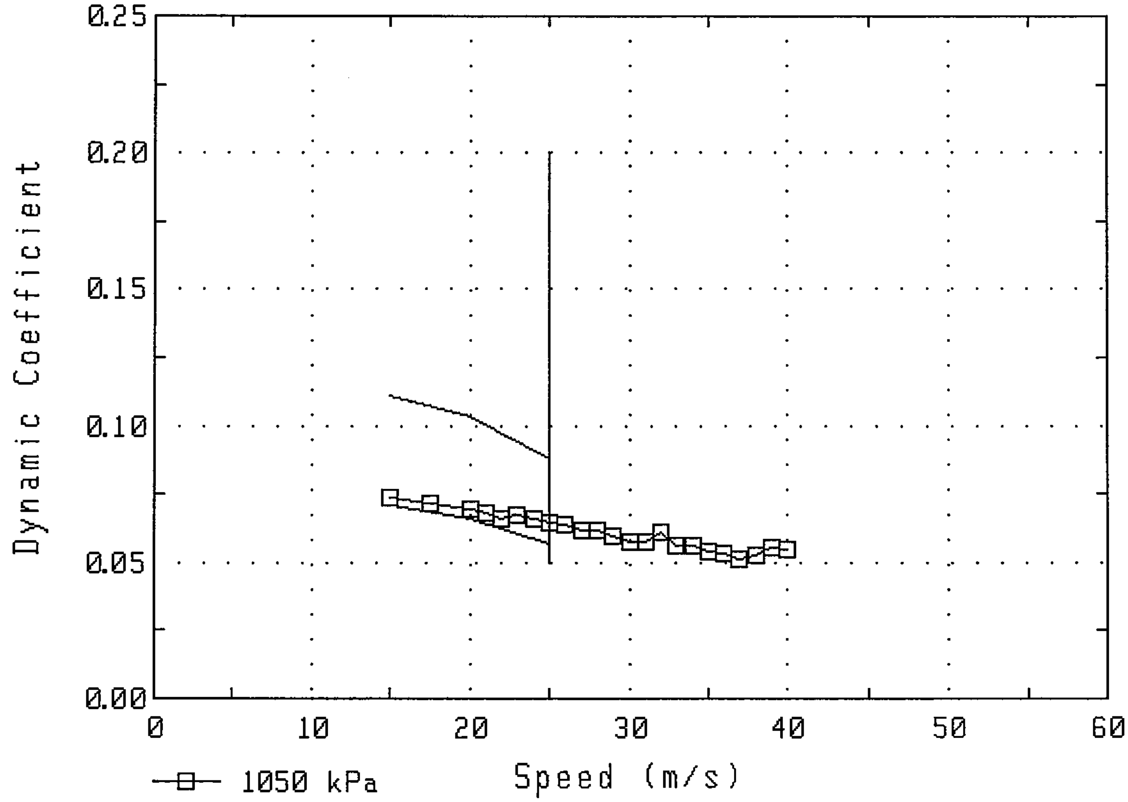
Total Wear (all measurements in mm): 0.008

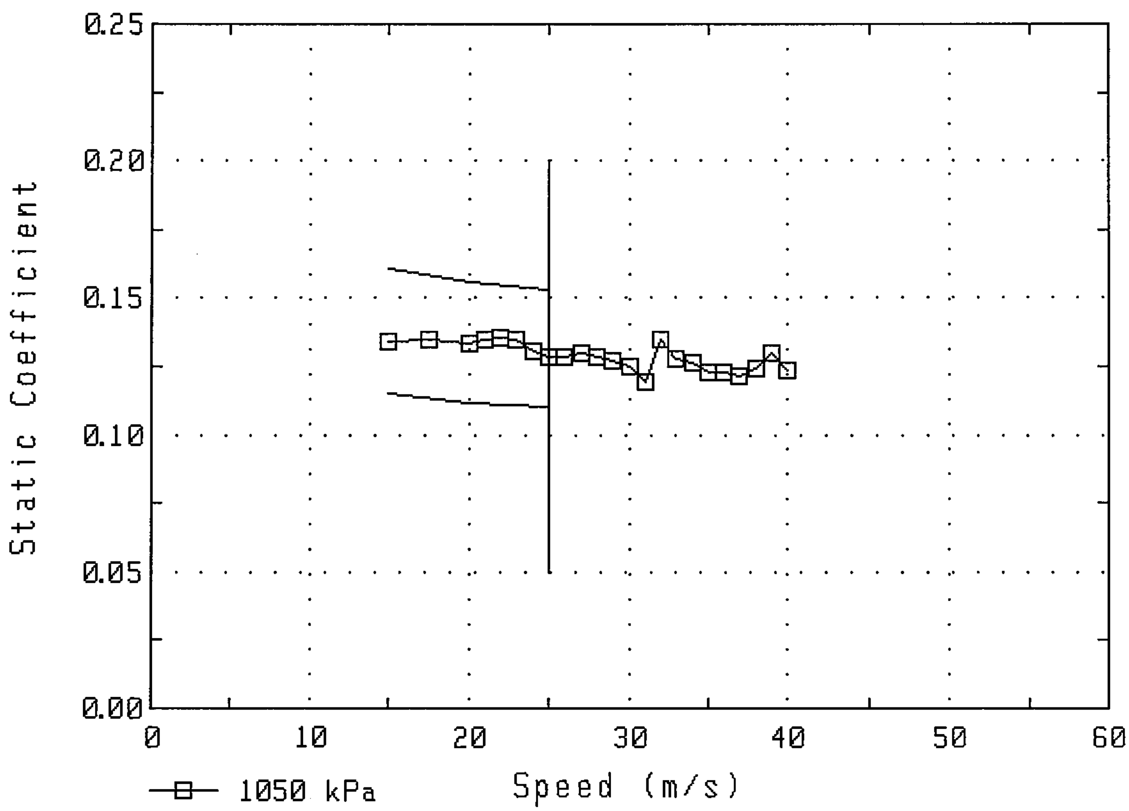


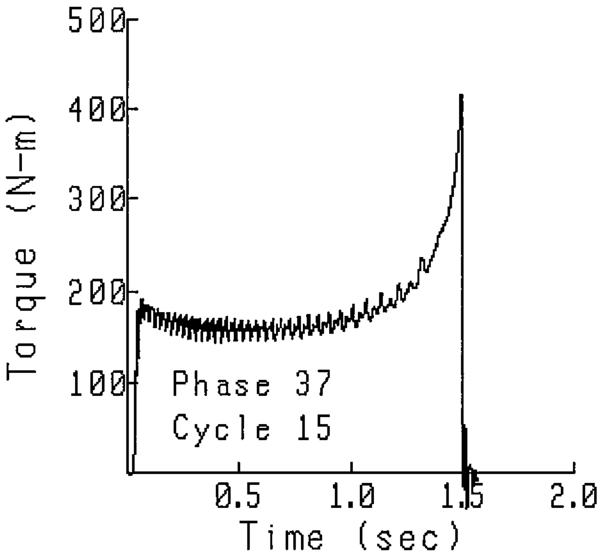
0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s



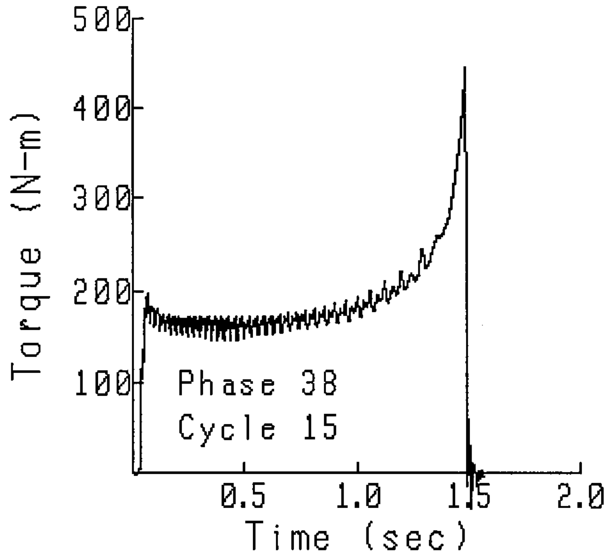
0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s


0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

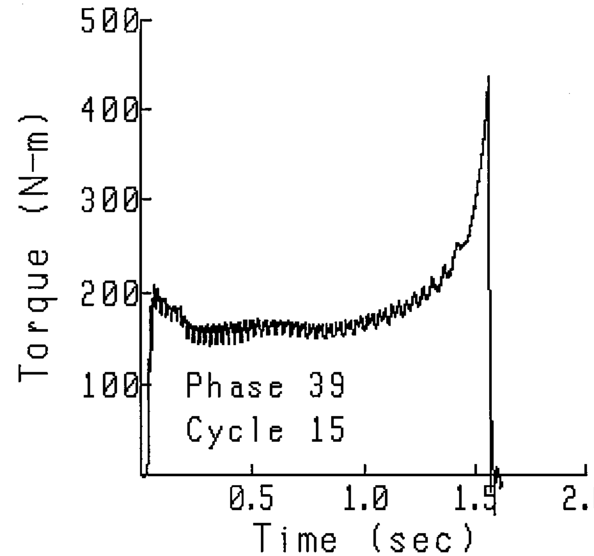

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa



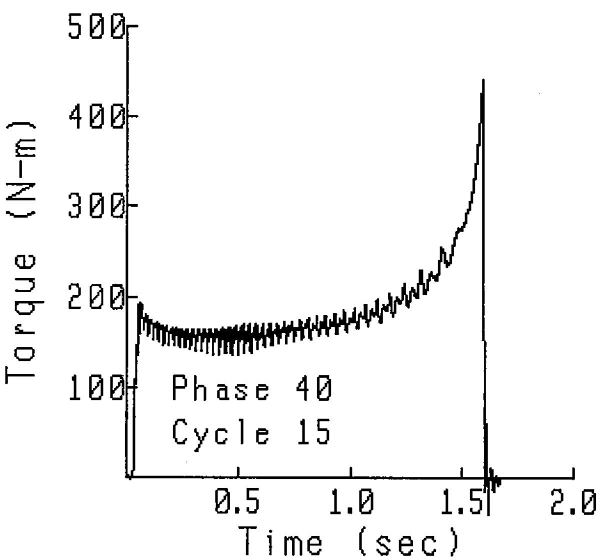
(35.0 m/s, 1049 kPa)



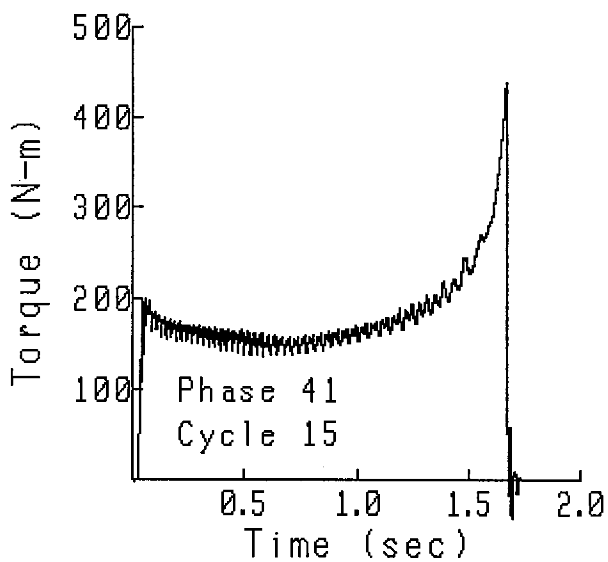
(36.0 m/s, 1048 kPa)



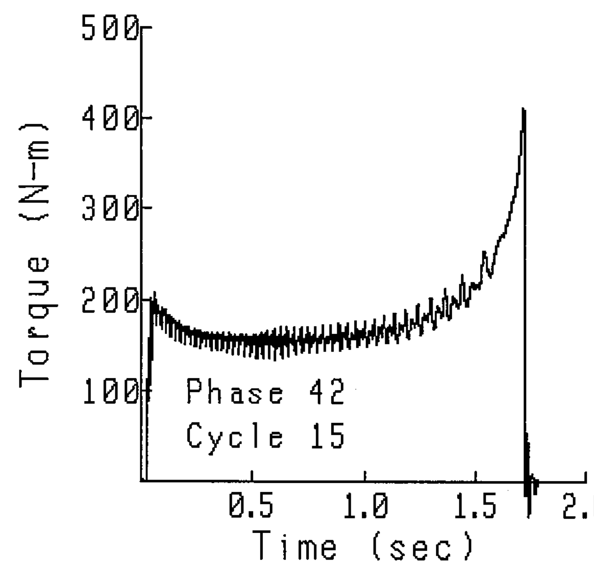
(37.0 m/s, 1051 kPa)



(38.0 m/s, 1049 kPa)



(39.0 m/s, 1050 kPa)

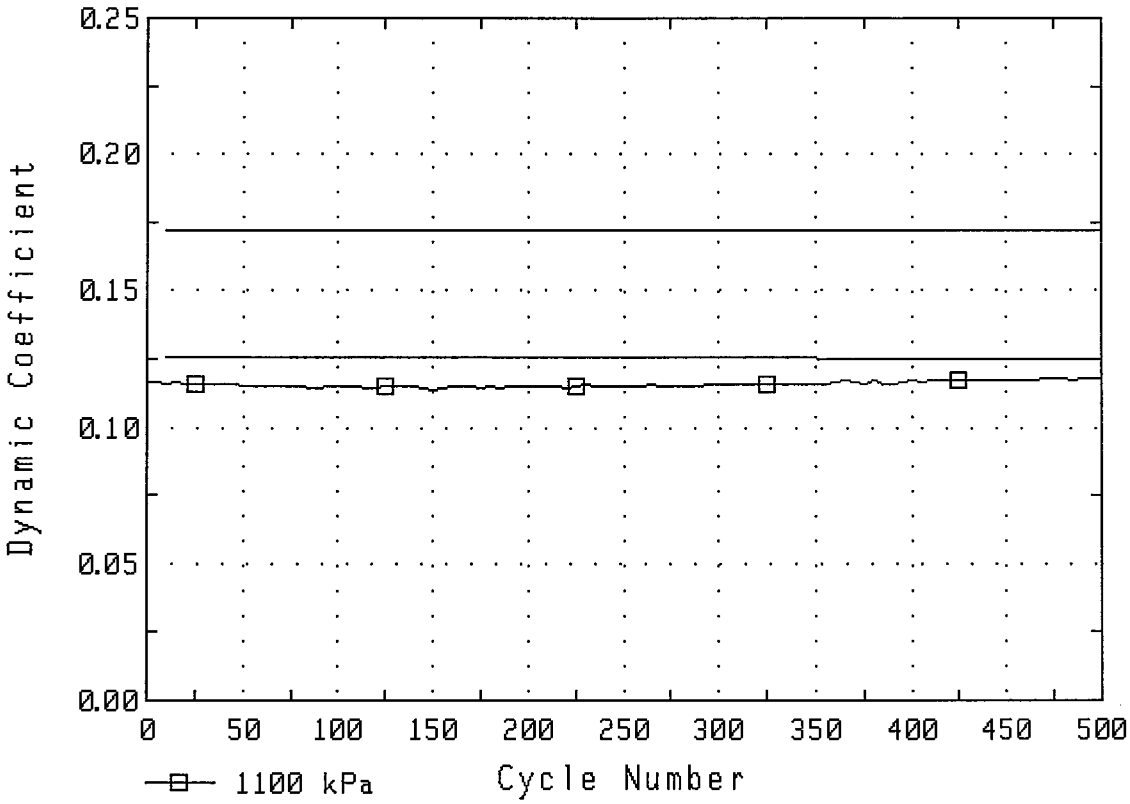


(40.0 m/s, 1050 kPa)

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO253071 / LO-253071

Test name:	A-103-J
Test date:	09/14/10
Test description:	J MACHINE LO253071
Oil type:	LO253071 / LO-253071
Viscosity:	0W-30
Miscellaneous:	
Software version:	1.40
Run name & desc:	J0508218 - LO253071
Run date:	09/16/10
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J"MACHINE OIL TEST LO253071 / LO-253071
Sequence name:	SEQ1222
Remarks:	Use 1Y0711 Disc and 1Y0726 Plate
Number of cycles run:	1126
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 $N\text{-}m\text{-}s^2$
Disc name & desc:	1Y0711 - Wheel Brake Paper
Material:	Raybestos 7902-1 Paper
Groove pattern:	2 - 37 Multiple Parallel
Miscellaneous:	Use with 1Y0726 Steel Plate
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	06MR928188
Remarks:	WHEEL BRAKE PAPER
Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	06MR928188
Remarks:	0.29 SURFACE FINISH
Report limit name:	LIM1222 - Reference run: J0508195
Limit file generated:	08/04/10
Report format name:	REP1222 - WHEEL BRAKE PAPER

Test: A-103-J Run: J0508218 Started on 09/16/10 at 07:28

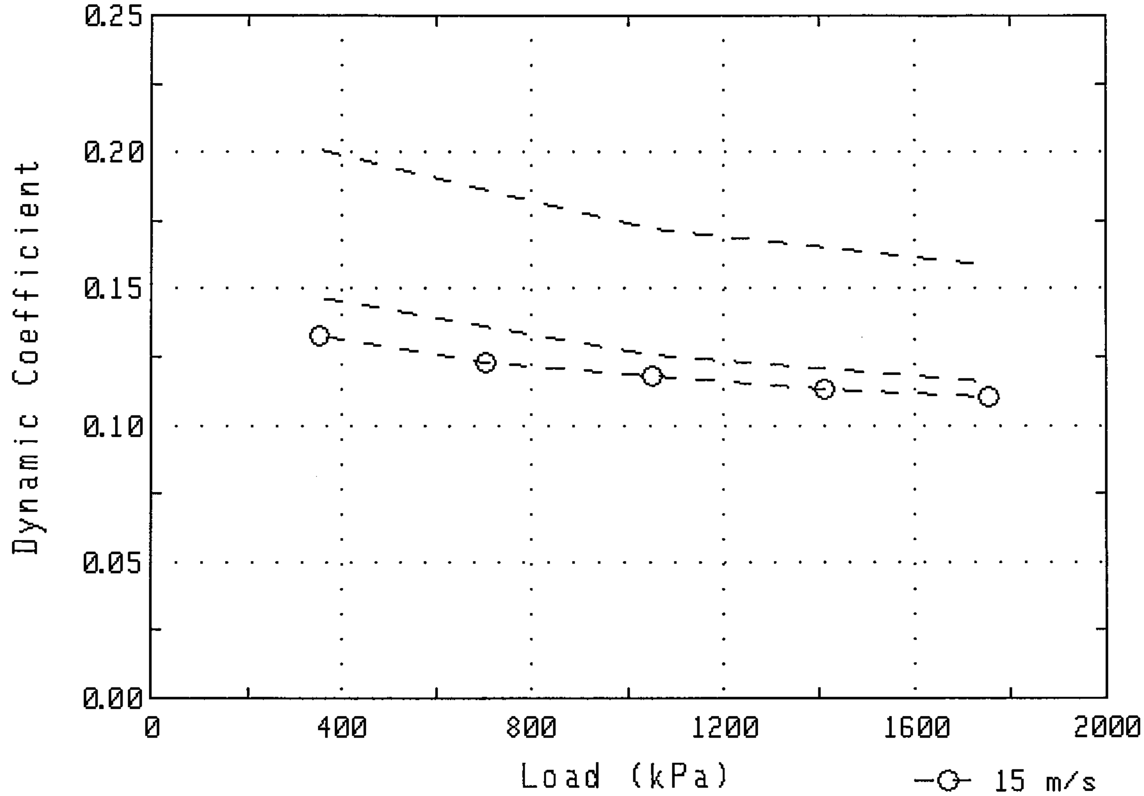


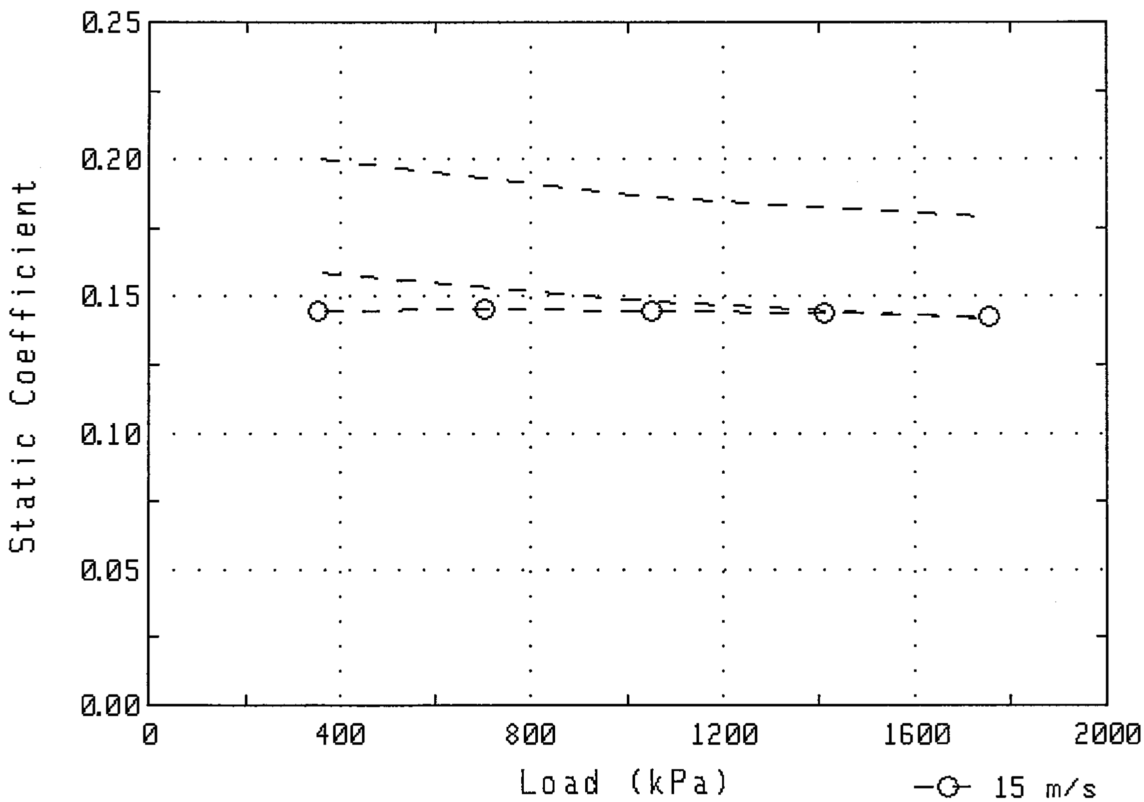
1Y0711 DISC
THICKNESS

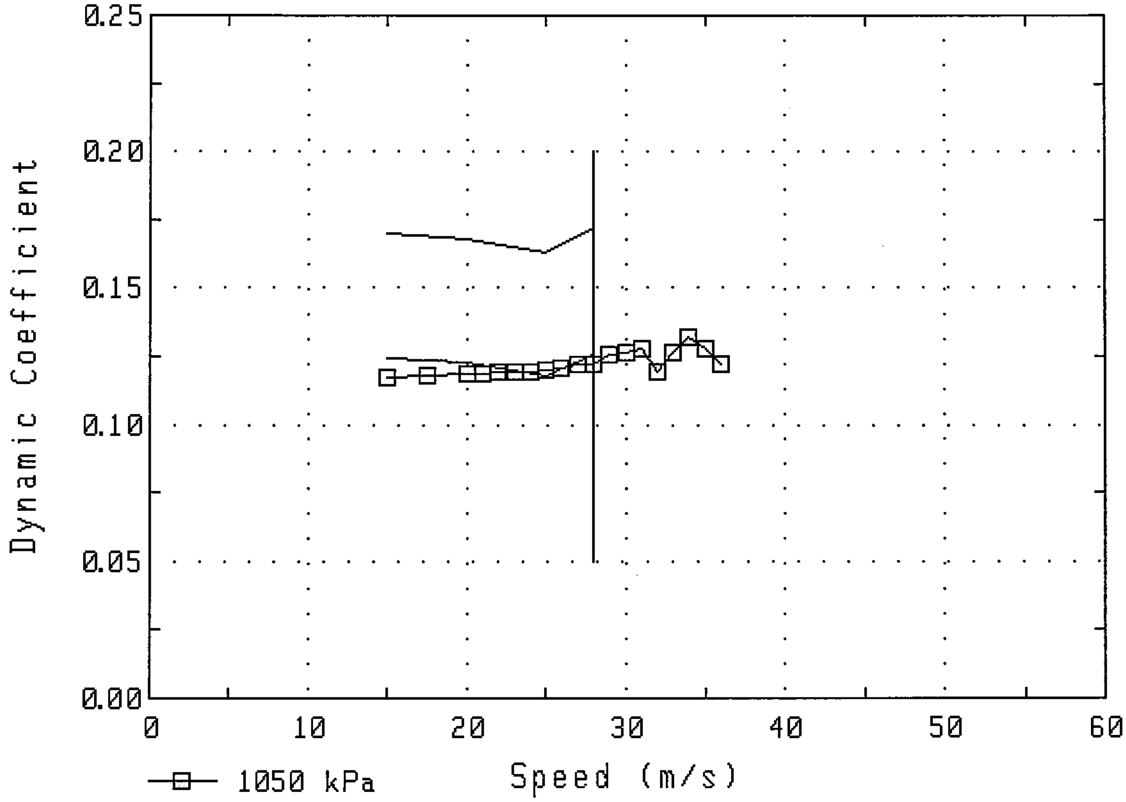
Loc	Outer Diameter M1	M2	M3	Inner Diameter M1	M2	M3
1	4.90	4.89	4.88	4.91	4.90	4.88
2	4.91	4.88	4.87	4.90	4.88	4.87
3	4.90	4.87	4.87	4.89	4.88	4.87
4	4.94	4.91	4.89	4.93	4.91	4.90
5	4.93	4.92	4.91	4.93	4.93	4.91
6	4.95	4.93	4.91	4.94	4.93	4.91
Avg	4.92	4.90	4.89	4.92	4.90	4.89

Compression set average wear: 0.017
M2 - M3 average Wear: 0.013

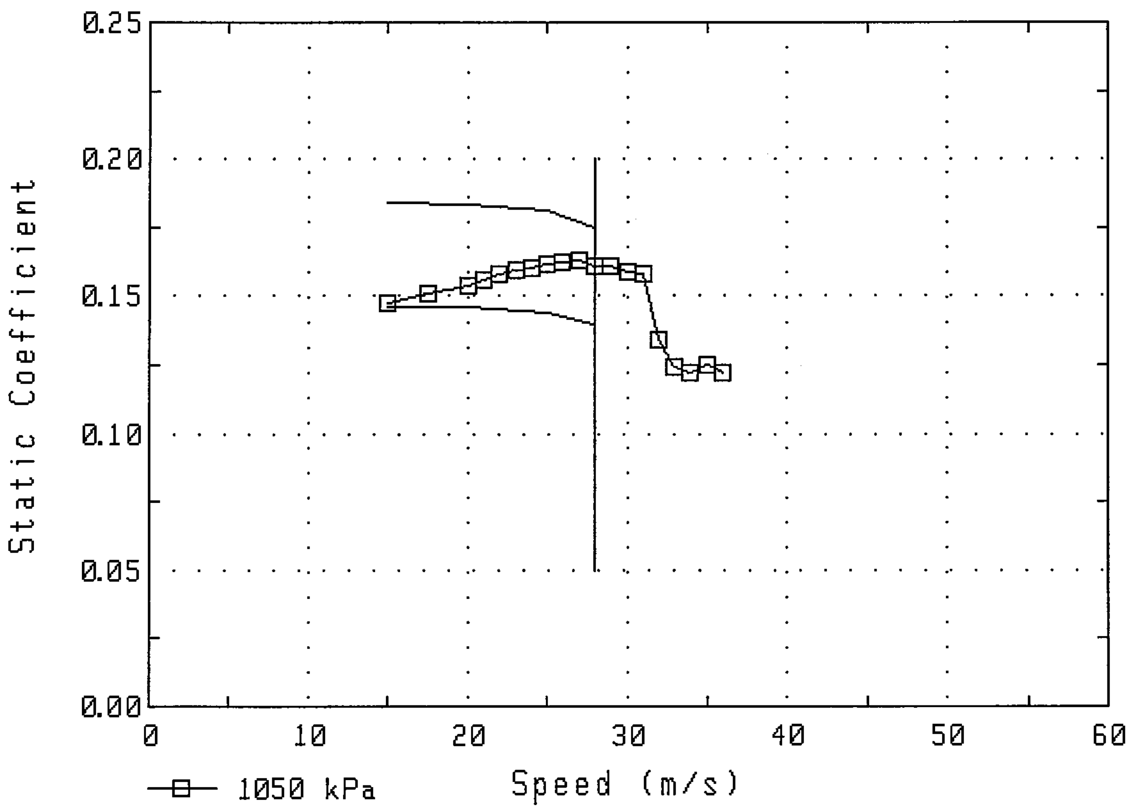
Total Wear (all measurements in mm): 0.030


0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

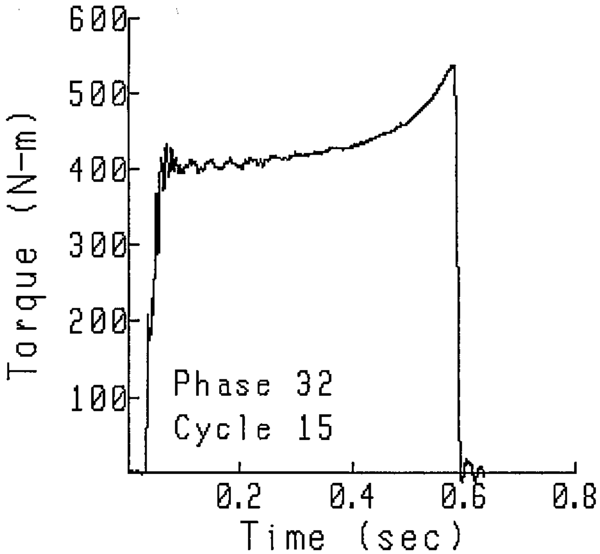

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s



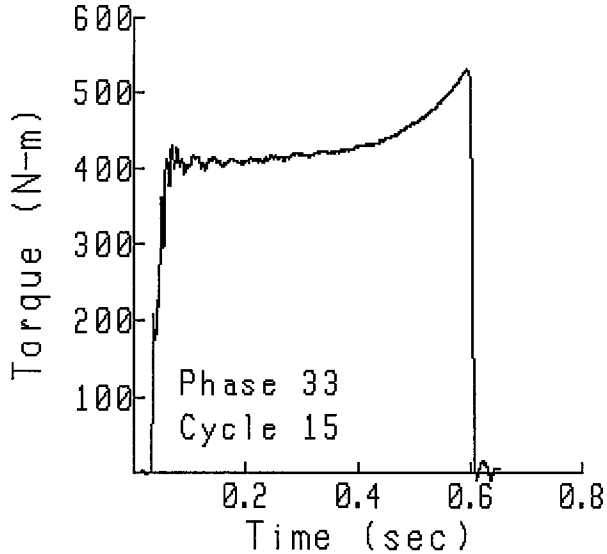
Dynamic Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)



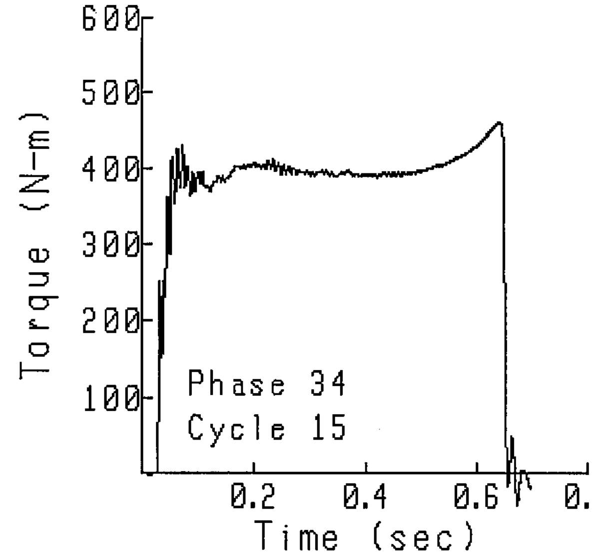
Static Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
1050 kPa
Speed (m/s)



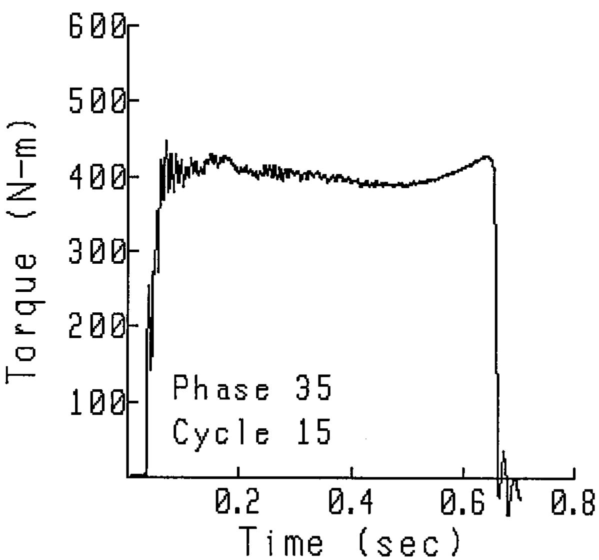
(30.0 m/s, 1052 kPa)



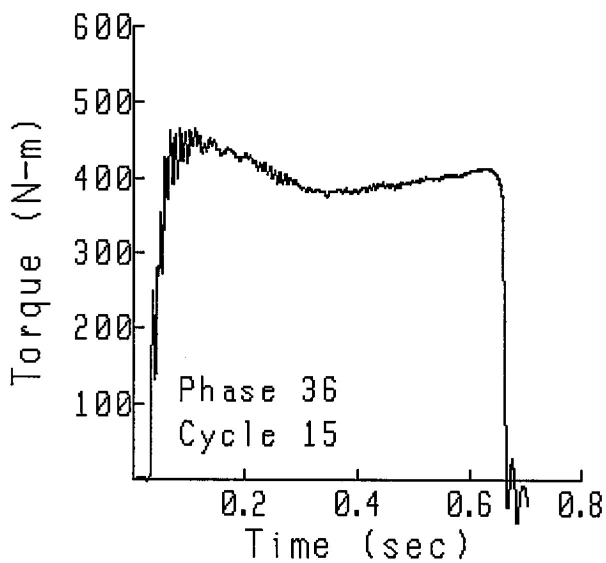
(31.0 m/s, 1047 kPa)



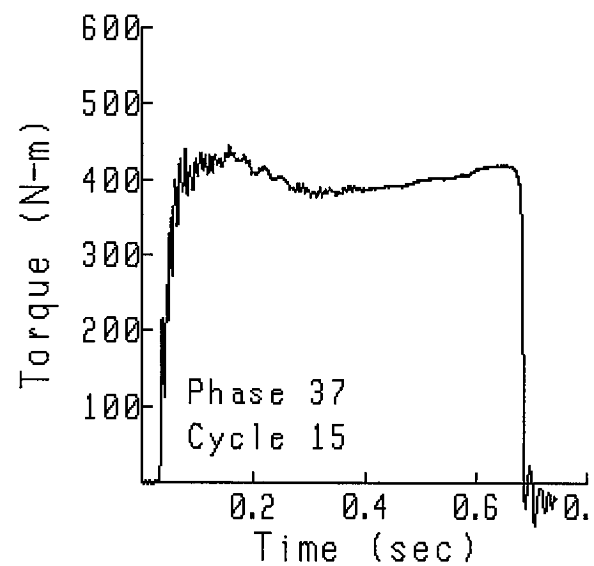
(32.0 m/s, 1056 kPa)



(33.0 m/s, 1050 kPa)



(34.0 m/s, 1051 kPa)



(35.0 m/s, 1052 kPa)

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO253071 / LO-253071

Test name:	A-103-J
Test date:	09/14/10
Test description:	J MACHINE LO253071
Oil type:	LO253071 / LO-253071
Viscosity:	0W-30
Miscellaneous:	
Software version:	1.40

Run name & desc:	J0508219 - LO253071
Run date:	09/17/10
Oil temperature:	115 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J"MACHINE OIL TEST LO253071 / LO-253071
Sequence name:	SEQFRRET
Remarks:	USE 1Y0709 DISC AND 1Y0726 PLATE (8E7351 GROUP)
Number of cycles run:	25100

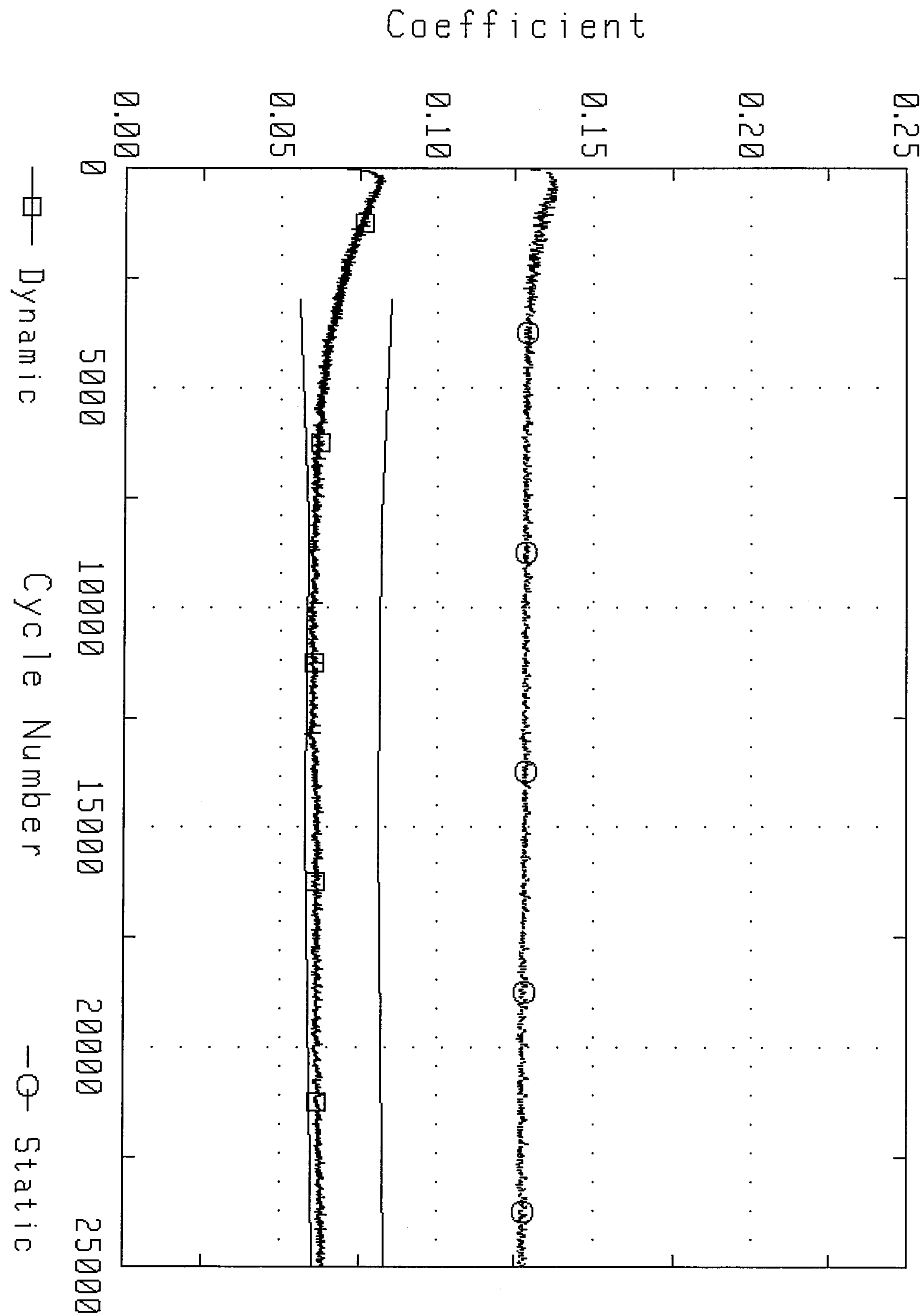
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 N-m-s^2

Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	12FE1-00010
Remarks:	SINTERED BRONZE

Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	12FE1-00010
Remarks:	0.18 SURFACE FINISH

Report limit name:	LIMFRRET - Reference run: J0508012
Limit file generated:	09/16/10
Report format name:	REPFRRET - FRICTION RETENTION

Test: A-103-J Run: J0508219 Started on 09/17/10 at 07:26



APPENDIX E2. – EVALUATION OF CANDIDATE LO254054 IN CATERPILLAR TO-4 TRANSMISSION TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Conducted for

ARMY LAB

Oil Code:
LO254054

Test Numbers:
VC70-A-104-J

September 28, 2010

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluations

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: ARMY LAB

Test start date: September 21, 2010
End of test date: September 28, 2010
Oil Code: LO254054

Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:		F		P			P
Dynamic Coefficient Vs. Load:		F		P			
Dynamic Coefficient Vs. Speed:		F		P			
Energy Limit:		P		P			
Static Coefficient Vs. Load:		P		F			
Static Coefficient Vs. Speed:		P		F			
Energy Limit:		P		P			
Total Wear:		0.008		0.039			
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand. The results are compared to TO-4 testing limits. 2009 Batch parts were used for all sequences except FRRET.

F = Fail
P = Pass
N/A = Not Applicable

SOUTHWEST RESEARCJH INSTITUTE
"J" MACHINE OIL TEST LO254054 / LO-254054

Test name:	A-104-J
Test date:	09/21/10
Test description:	J MACHINE LO254054
Oil type:	LO254054 / LO-254054
Viscosity:	0W-20
Miscellaneous:	
Software version:	1.40

Run name & desc:	J0508220 - LO254054
Run date:	09/22/10
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J"MACHINE OIL TEST LO254054 / LO-254054
Sequence name:	SEQ1220
Remarks:	Use 1Y0709 Disc and 8E4095 Plate
Number of cycles run:	1050

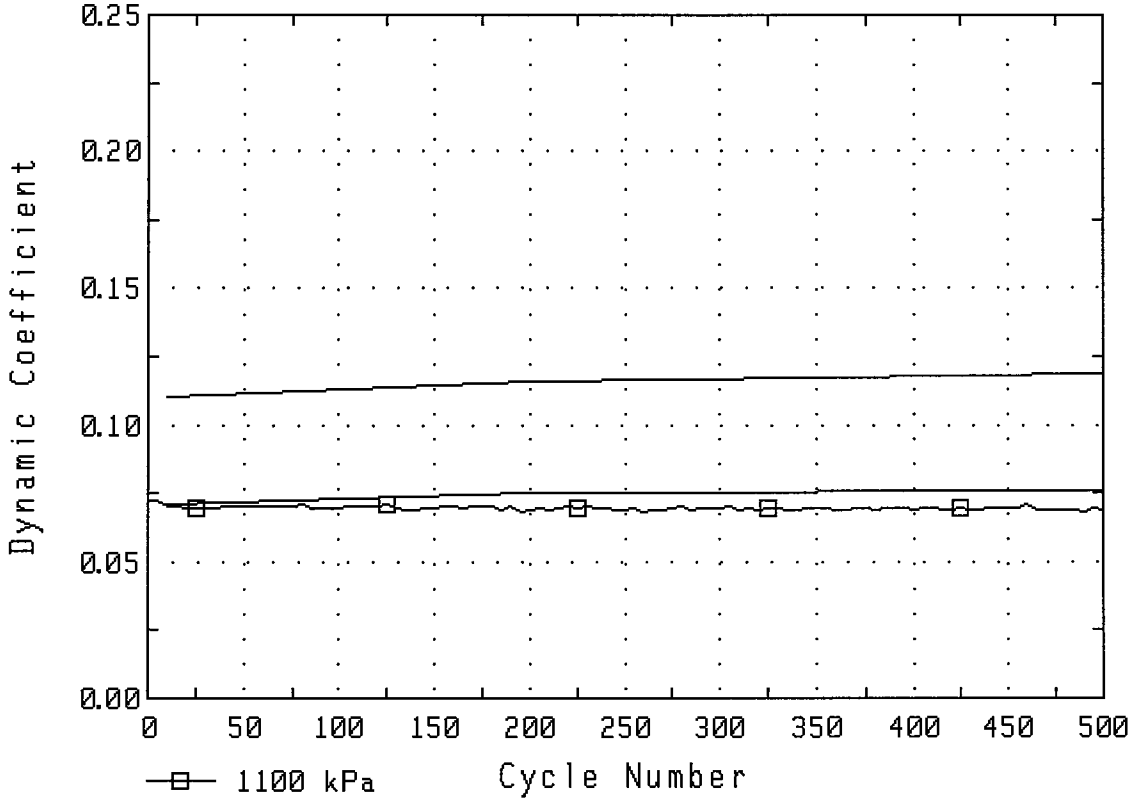
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 N-m-s^2

Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	007080C800012
Remarks:	SINTERED BRONZE

Plate name & desc:	8E4095 - Steel Plate
Surface:	0.70 to 1.00 micron Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	007080C800012
Remarks:	0.85 SURFACE FINISH

Report limit name:	LIM1220 - Reference run: J0508081
Limit file generated:	08/04/10
Report format name:	REP1220 - SINTERED BRONZE

Test: A-104-J Run: J0508220 Started on 09/22/10 at 07:25



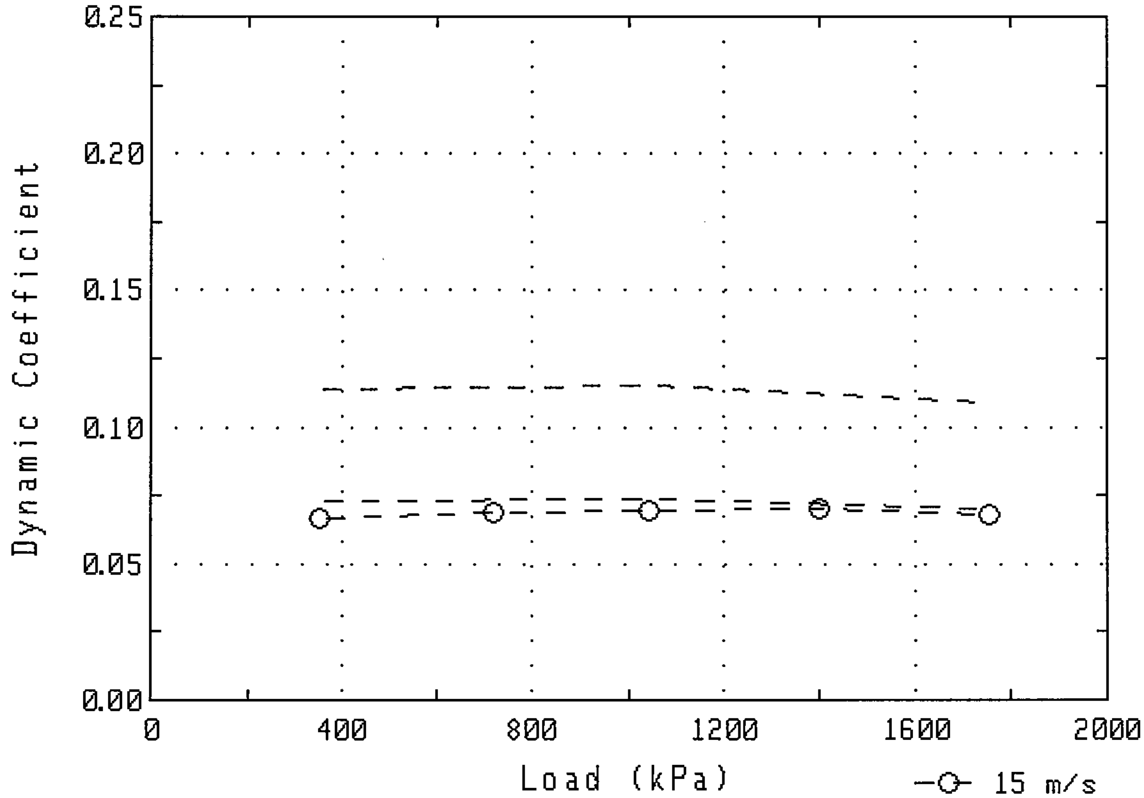
1Y0709 DISC
THICKNESS

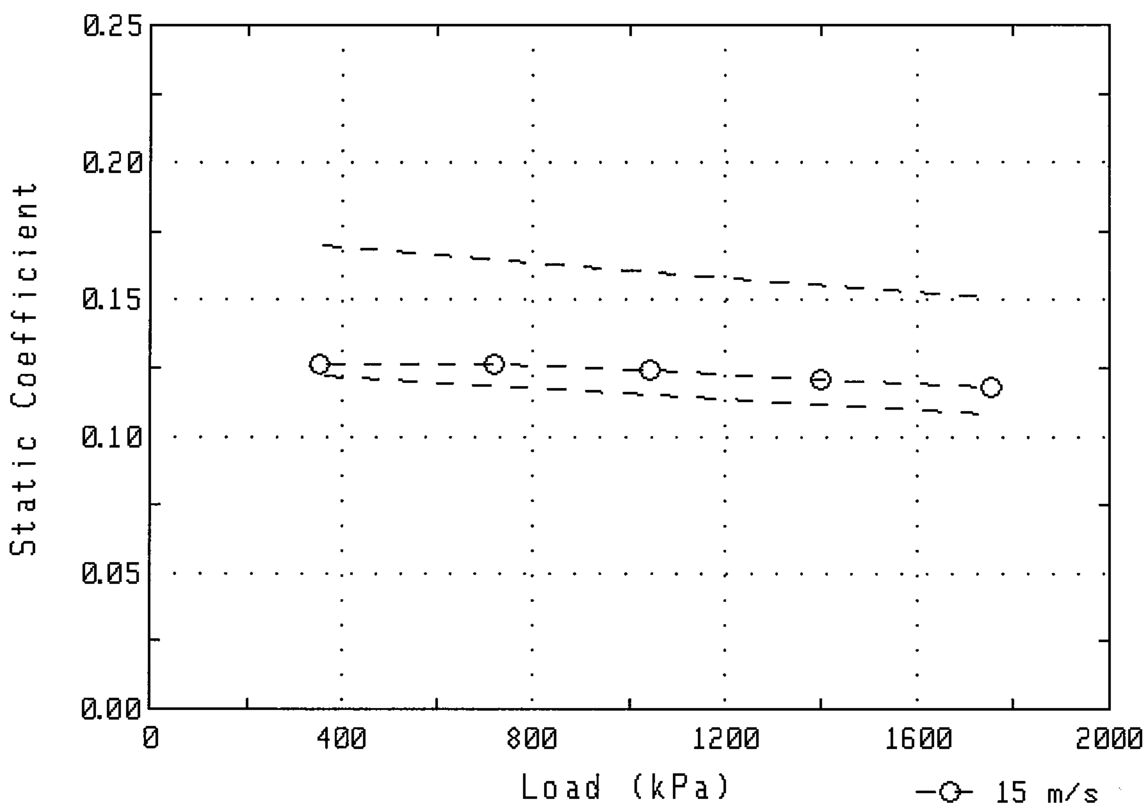
Loc	Outer Diameter M1	M2	M3	Inner Diameter M1	M2	M3
1	4.92	4.92	4.91	4.92	4.92	4.91
2	4.93	4.92	4.92	4.93	4.92	4.92
3	4.92	4.92	4.91	4.92	4.92	4.92
4	4.92	4.92	4.92	4.92	4.92	4.91
5	4.93	4.93	4.92	4.91	4.91	4.91
6	4.92	4.92	4.91	4.93	4.92	4.91
Avg	4.92	4.92	4.92	4.92	4.92	4.91

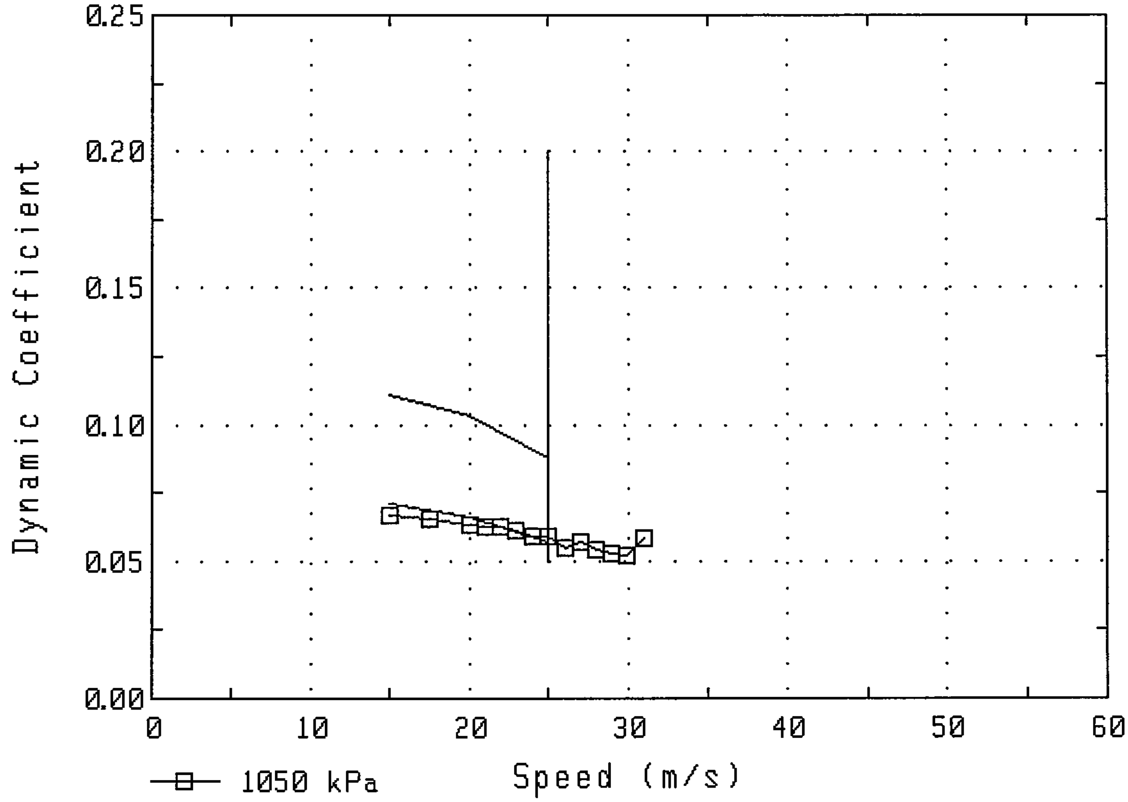
Compression set average wear: 0.002
M2 - M3 average Wear: 0.006

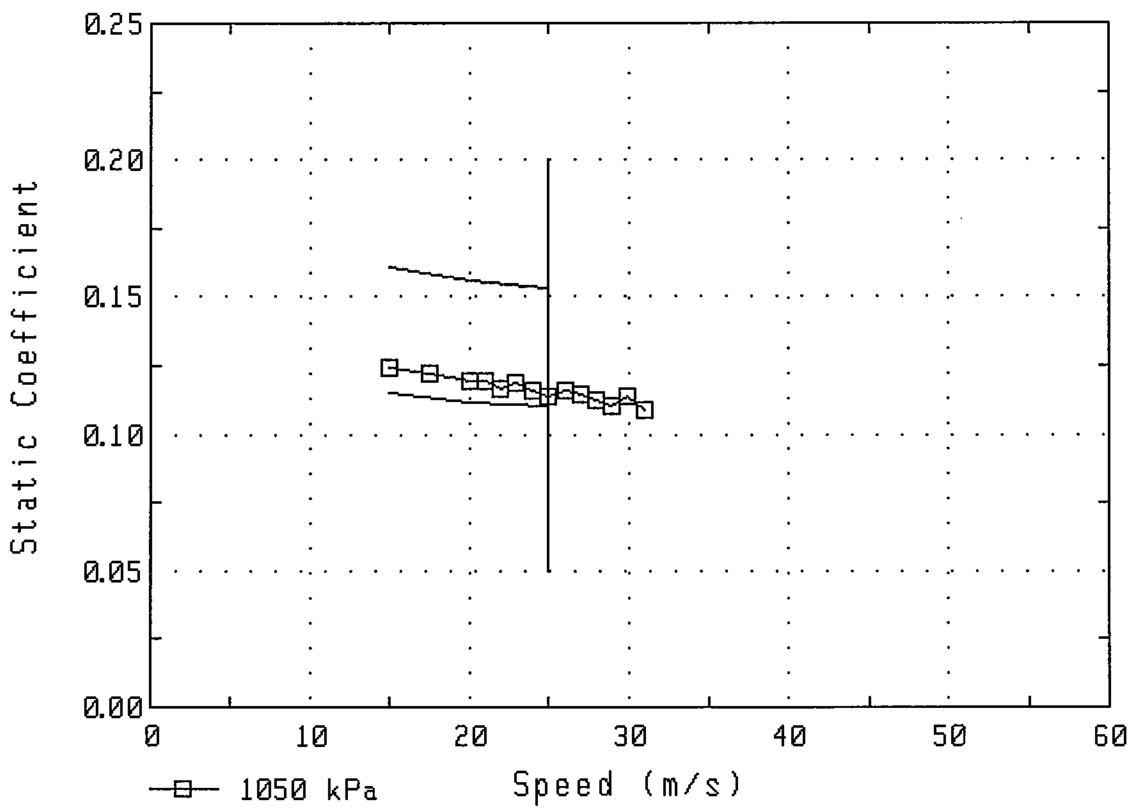
Total Wear (all measurements in mm): 0.008

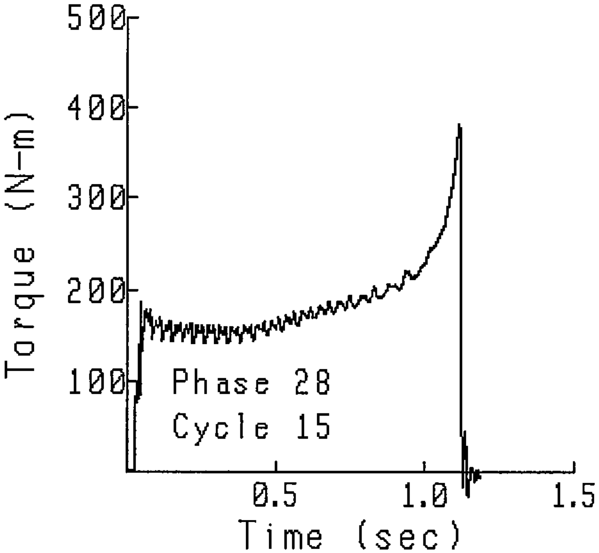
Test: A-104-J Run: J0508220 Started on 09/22/10 at 07:25



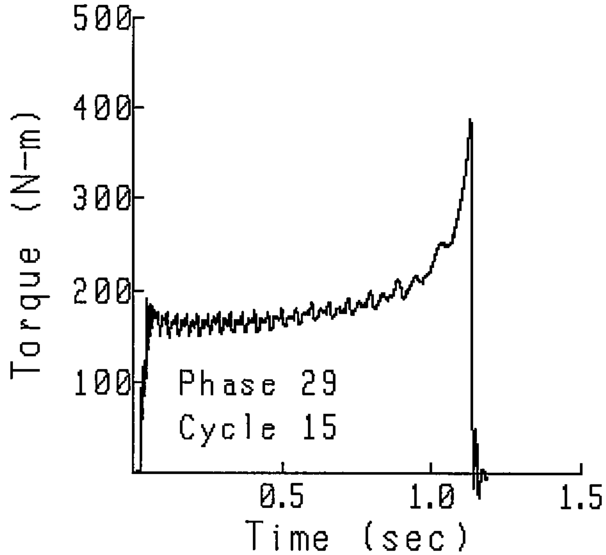



Dynamic Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

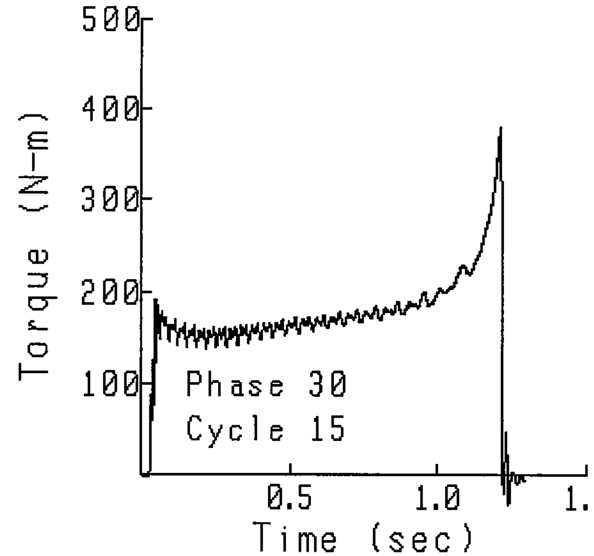

Static Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa



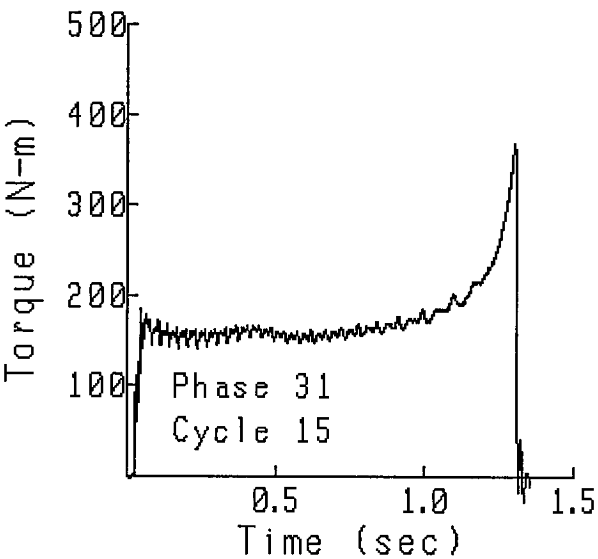
(26.0 m/s, 1048 kPa)



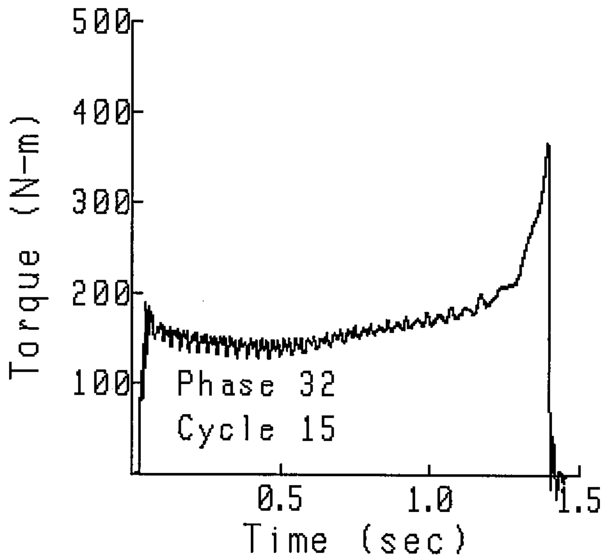
(27.0 m/s, 1049 kPa)



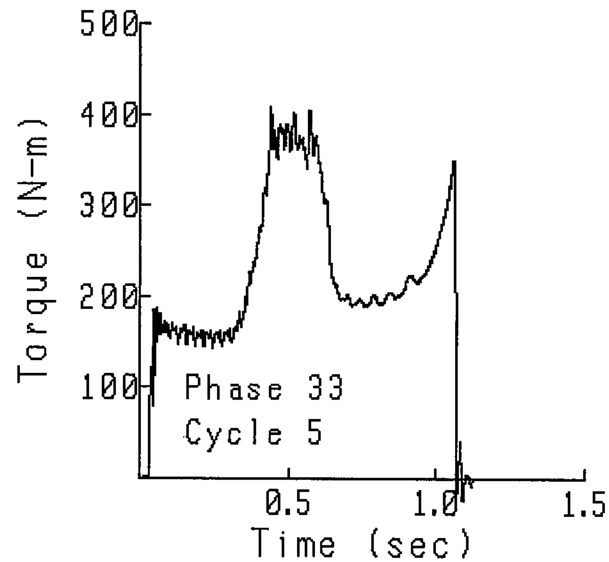
(28.0 m/s, 1053 kPa)



(29.0 m/s, 1050 kPa)



(30.0 m/s, 1049 kPa)



(31.0 m/s, 1059 kPa)

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO254054 / LO-254054

Test name:	A-104-J
Test date:	09/21/10
Test description:	J MACHINE LO254054
Oil type:	LO254054 / LO-254054
Viscosity:	0W-20
Miscellaneous:	
Software version:	1.40

Run name & desc:	J0508221 - LO254054
Run date:	09/23/10
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	JM
Remarks:	J MACHINE OIL TEST LO254054 / LO-254054
Sequence name:	SEQ1222
Remarks:	Use 1Y0711 Disc and 1Y0726 Plate
Number of cycles run:	1163

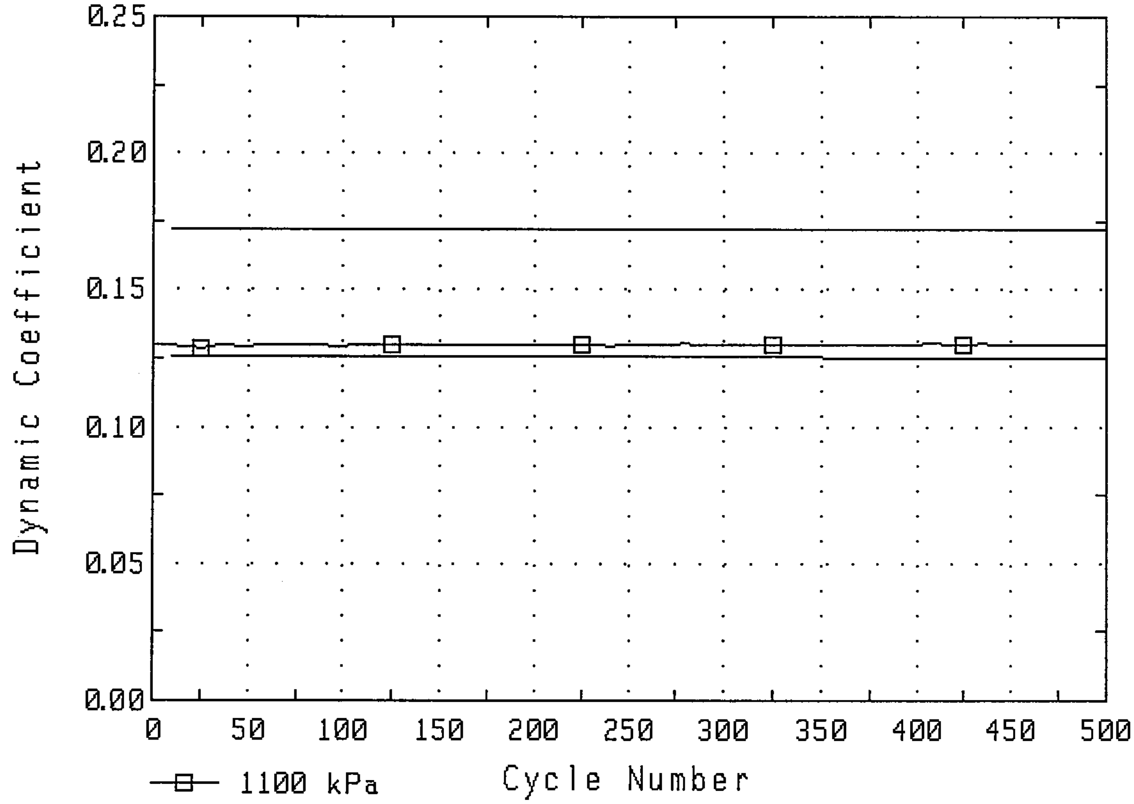
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 $N\text{-}m\text{-}s^2$

Disc name & desc:	1Y0711 - Wheel Brake Paper
Material:	Raybestos 7902-1 Paper
Groove pattern:	2 - 37 Multiple Parallel
Miscellaneous:	Use with 1Y0726 Steel Plate
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	06MR928188
Remarks:	WHEEL BRAKE PAPER

Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	06MR928188
Remarks:	0.25 SURFACE FINISH

Report limit name:	LIM1222 - Reference run: J0508195
Limit file generated:	08/04/10
Report format name:	REP1222 - WHEEL BRAKE PAPER

Test: A-104-J Run: J0508221 Started on 09/23/10 at 07:28

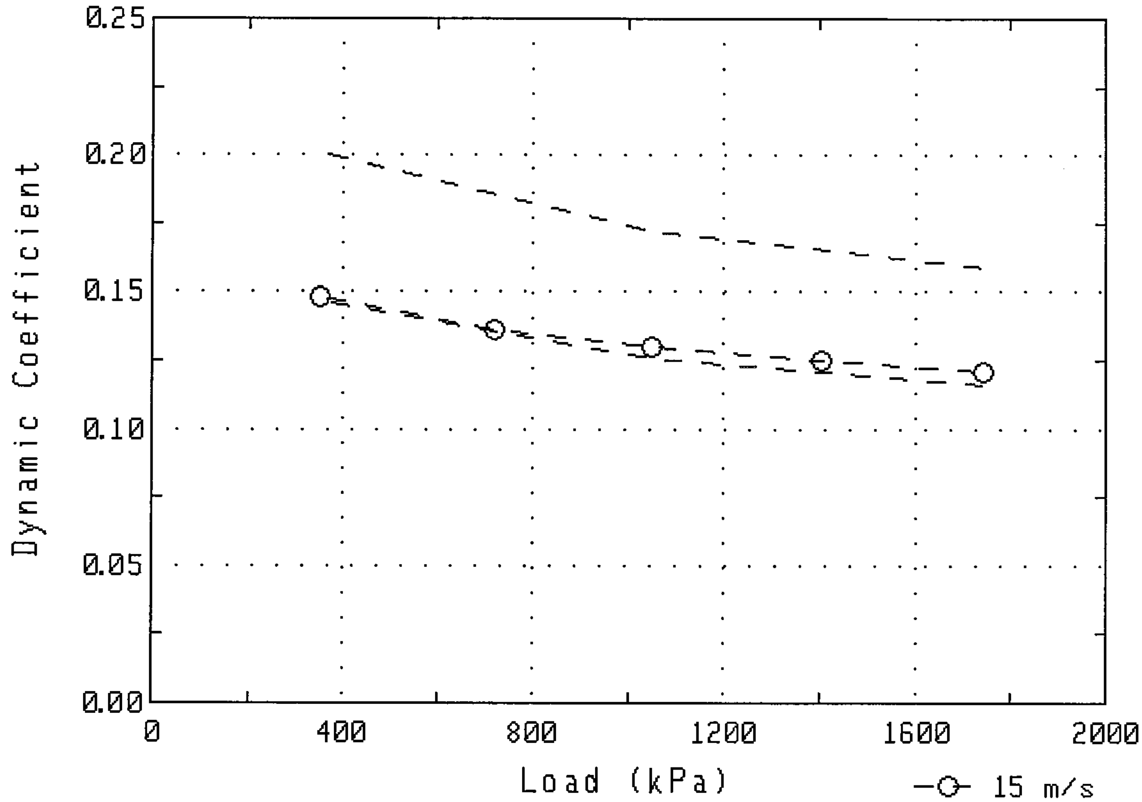


1Y0711 DISC
THICKNESS

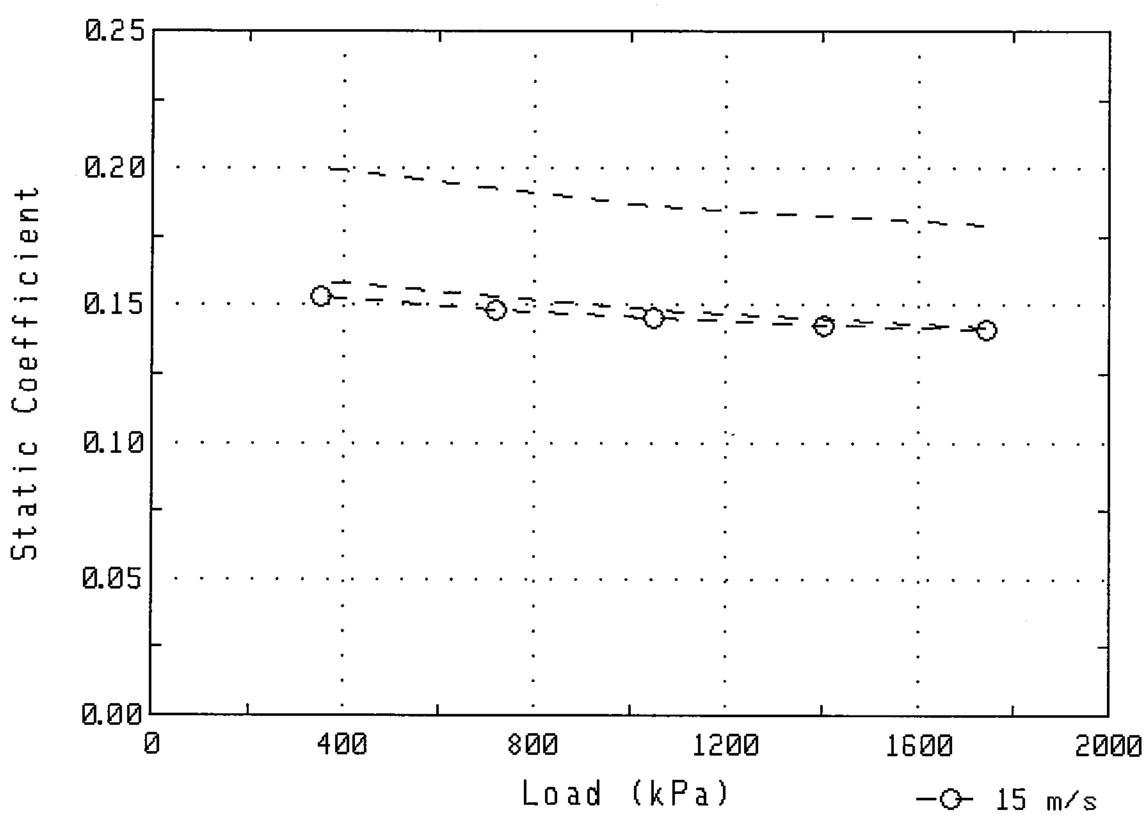
Loc	Outer Diameter M1	M2	M3	Inner Diameter M1	M2	M3
1	4.94	4.90	4.89	4.95	4.90	4.89
2	4.92	4.88	4.88	4.92	4.88	4.88
3	4.91	4.87	4.87	4.91	4.88	4.88
4	4.89	4.86	4.85	4.89	4.86	4.85
5	4.90	4.87	4.86	4.90	4.87	4.87
6	4.90	4.88	4.88	4.91	4.88	4.87
Avg	4.91	4.88	4.87	4.91	4.88	4.87

Compression set average wear: 0.034
M2 - M3 average Wear: 0.005

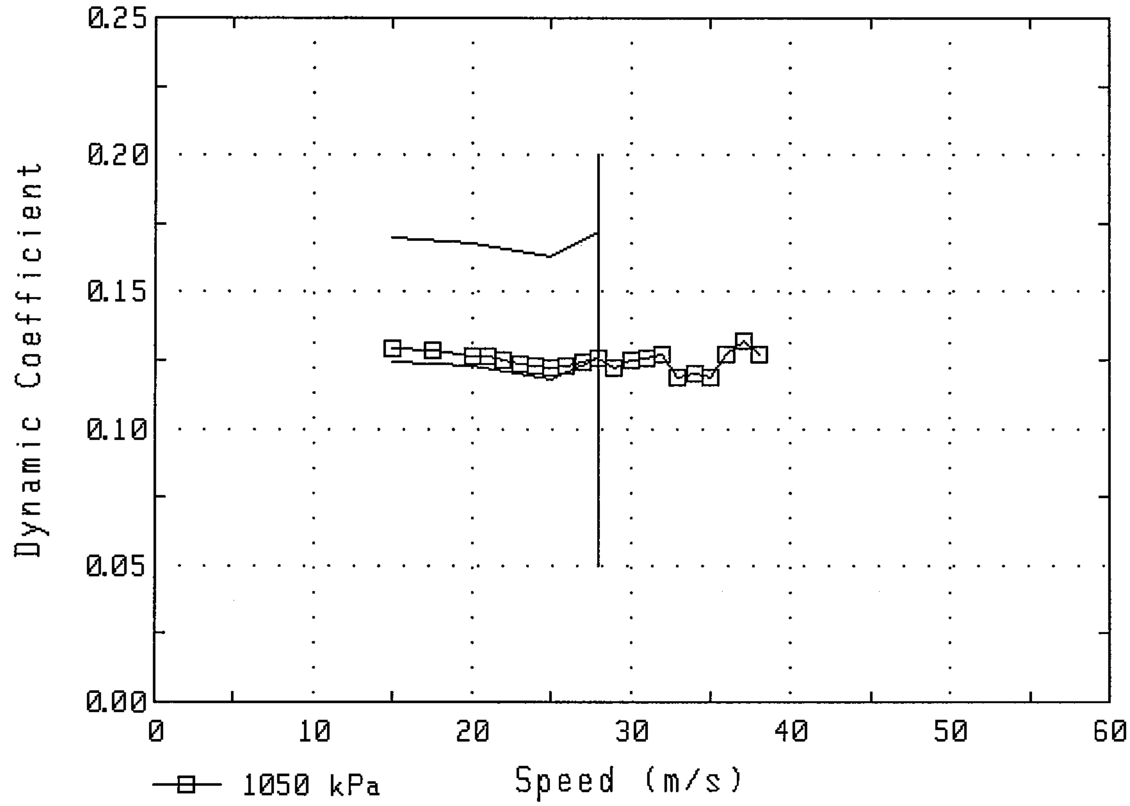
Total Wear (all measurements in mm): 0.039

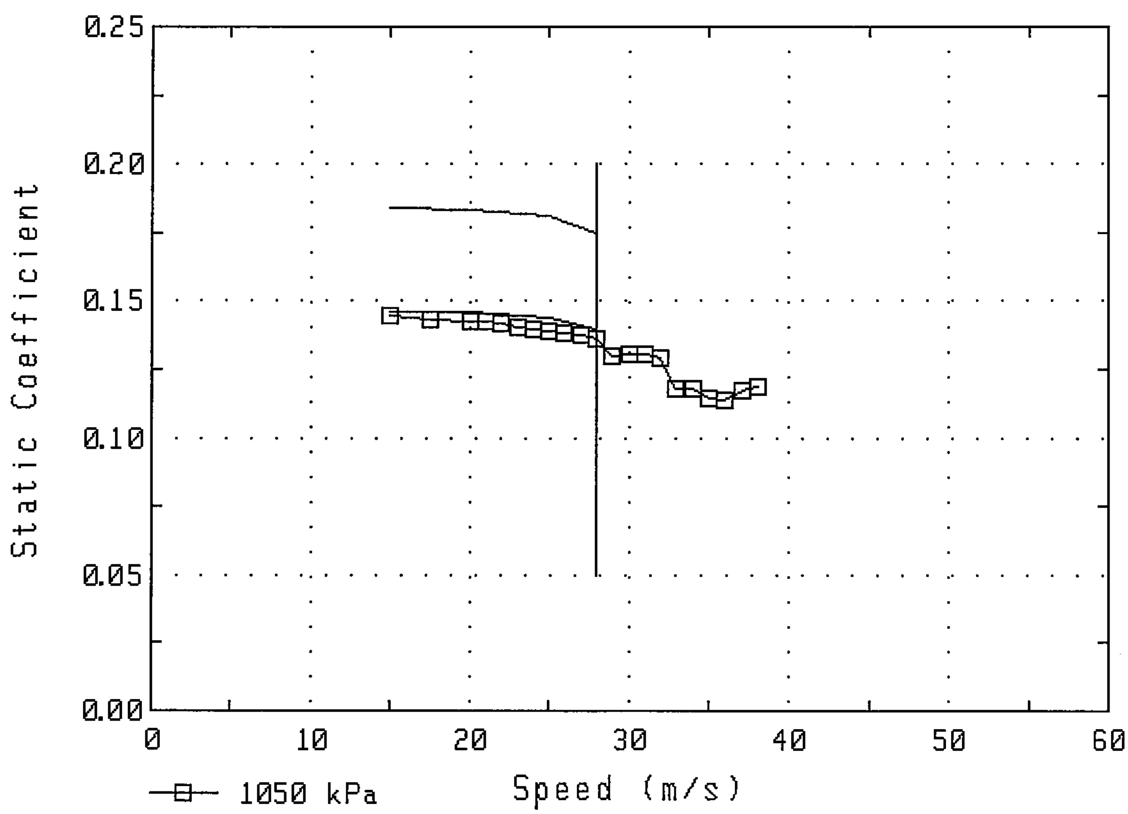


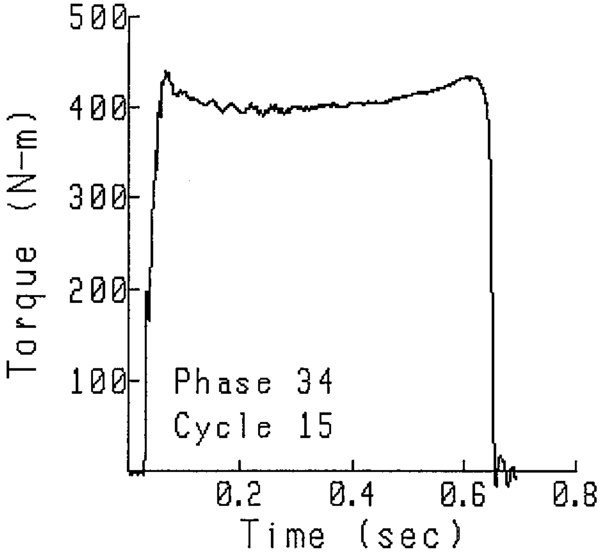
0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s



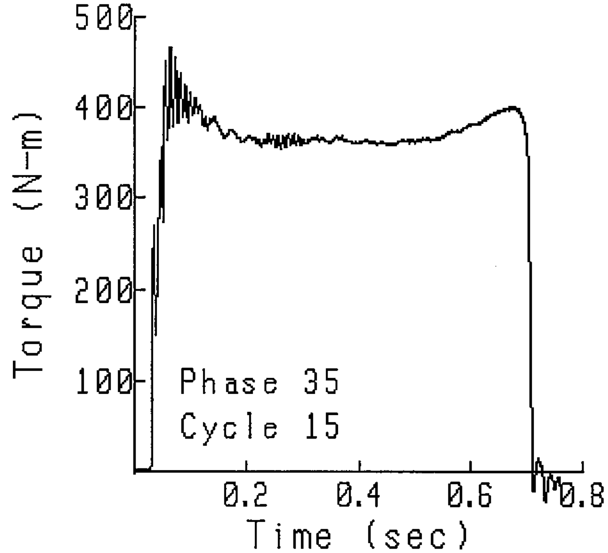
0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s


0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

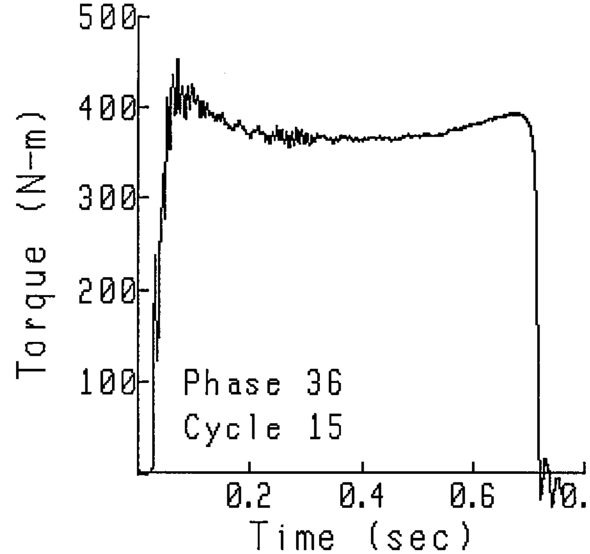

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa



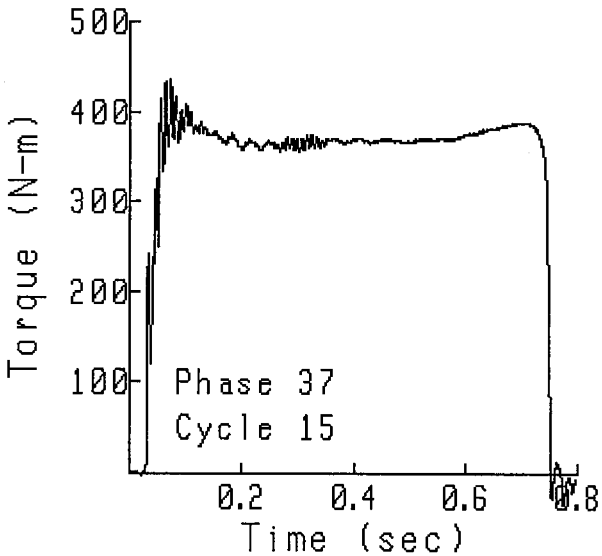
(32.0 m/s, 1051 kPa)



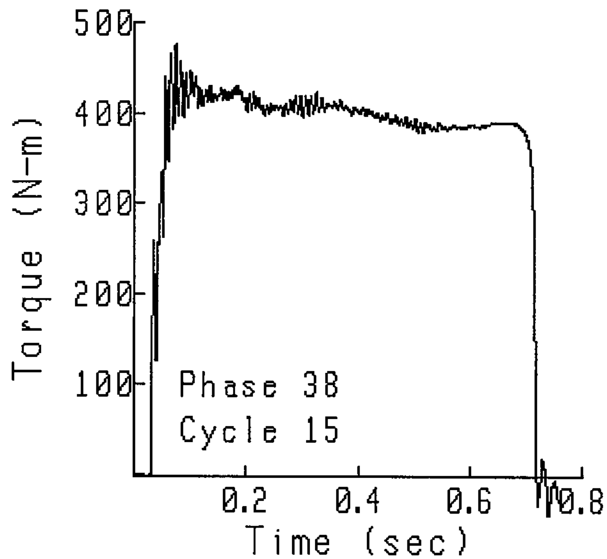
(33.0 m/s, 1053 kPa)



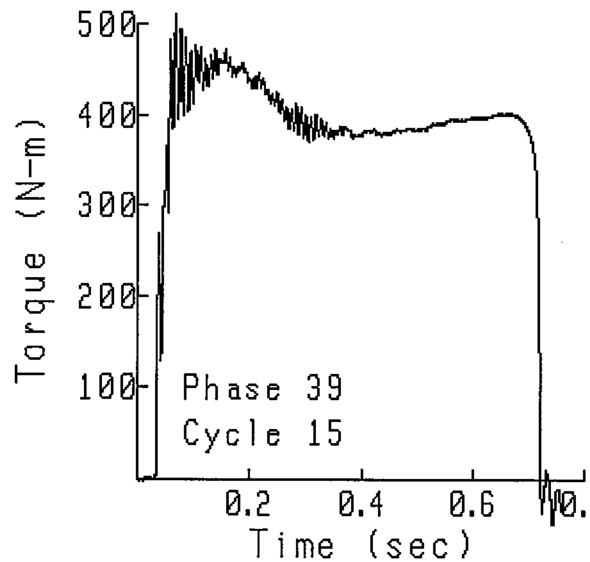
(34.0 m/s, 1050 kPa)



(35.0 m/s, 1052 kPa)



(36.0 m/s, 1050 kPa)



(37.0 m/s, 1050 kPa)

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO254054 / LO-254054

Test name:	A-104-J
Test date:	09/21/10
Test description:	J MACHINE LO254054
Oil type:	LO254054 / LO-254054
Viscosity:	0W-20
Miscellaneous:	
Software version:	1.40

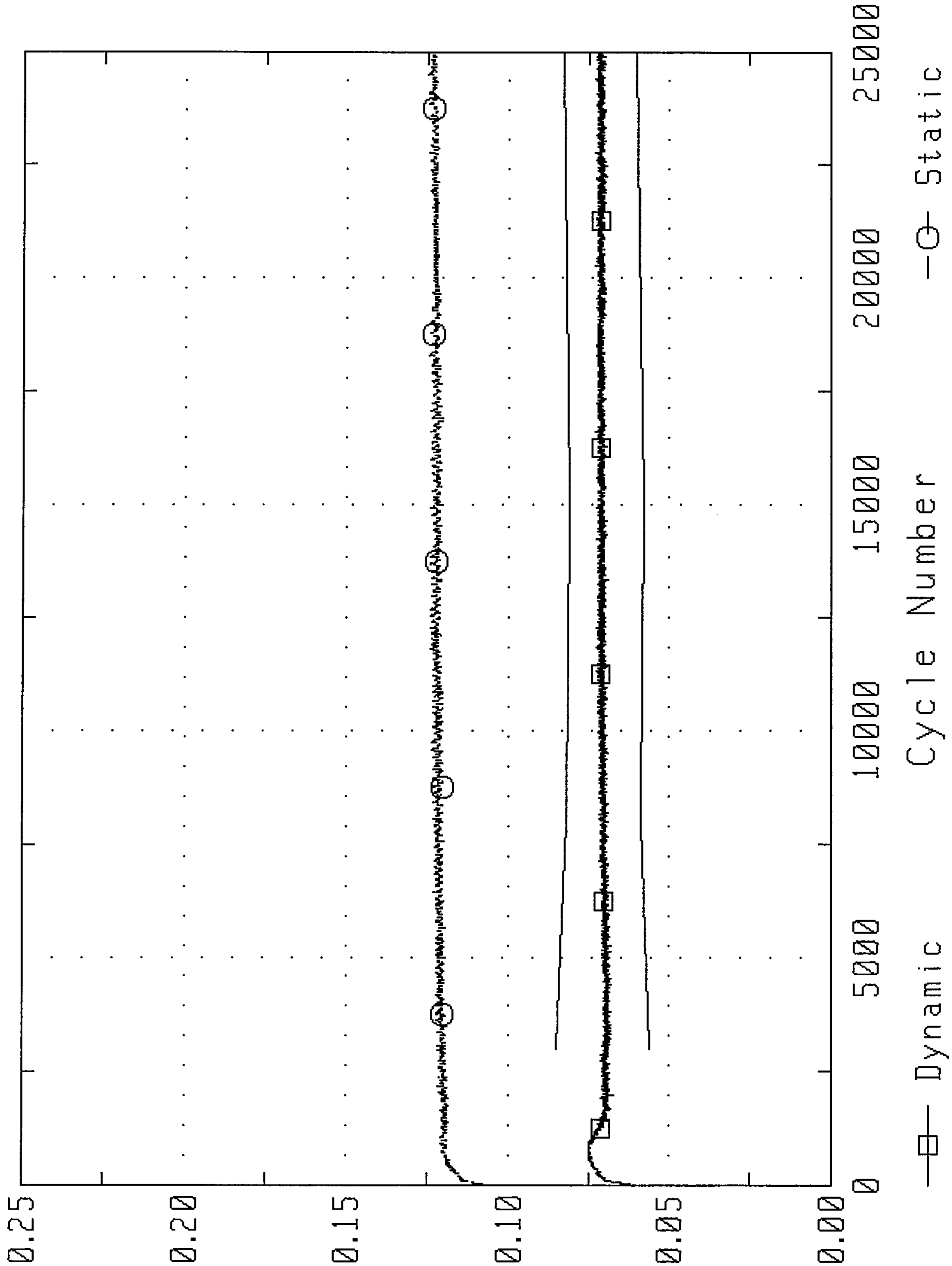
Run name & desc:	J0508222 - LO254054
Run date:	09/23/10
Oil temperature:	115 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	J MACHINE OIL TEST LO254054 / LO-254054
Sequence name:	SEQFRRET
Remarks:	USE 1Y0709 DISC AND 1Y0726 PLATE (8E7351 GROUP)
Number of cycles run:	25100

Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 $N\text{-}m\text{-}s^2$

Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	12FE1-00010
Remarks:	SINTERED BRONZE

Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	12FE1-00010
Remarks:	0.20 SURFACE FINISH

Report limit name:	LIMFRRET - Reference run: J0508012
Limit file generated:	09/16/10
Report format name:	REPFRRET - FRICTION RETENTION



Test: A-104-J Run: J0508222 Started on 09/23/10 at 15:53

APPENDIX E3. – EVALUATION OF CANDIDATE LO25033 IN CATERPILLAR TO-4 TRANSMISSION TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Conducted for

ARMY LAB

Oil Code:
LO250033

Test Numbers:
VC70-A-101-J

September 6, 2010

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluations

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: CHEVRON ORONITE COMPANY LLC

Test start date: August 31, 2010
End of test date: Septemeber 6, 2010
Oil Code: LO250033

Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:		P		F			P
Dynamic Coefficient Vs. Load:		P		F			
Dynamic Coefficient Vs. Speed:		P		P			
Energy Limit:		P		P			
Static Coefficient Vs. Cycle:							N/A
Static Coefficient Vs. Load:		P		P			
Static Coefficient Vs. Speed:		P		P			
Energy Limit:		P		P			
Total Wear:		0.014		0.028			
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand. The results are compared to TO-4 testing limits.2009 batch parts were used for all sequences except for FRRET.

F = Fail
P = Pass
N/A = Not Applicable

Southwest Research Institute
"J" MACHINE OIL TEST LO250033 / LO-250033

Test name:	A-101-J
Test date:	08/30/10
Test description:	J Machine LO250033
Oil type:	LO250033 / LO-250033
Viscosity:	5w-30
Miscellaneous:	
Software version:	1.40

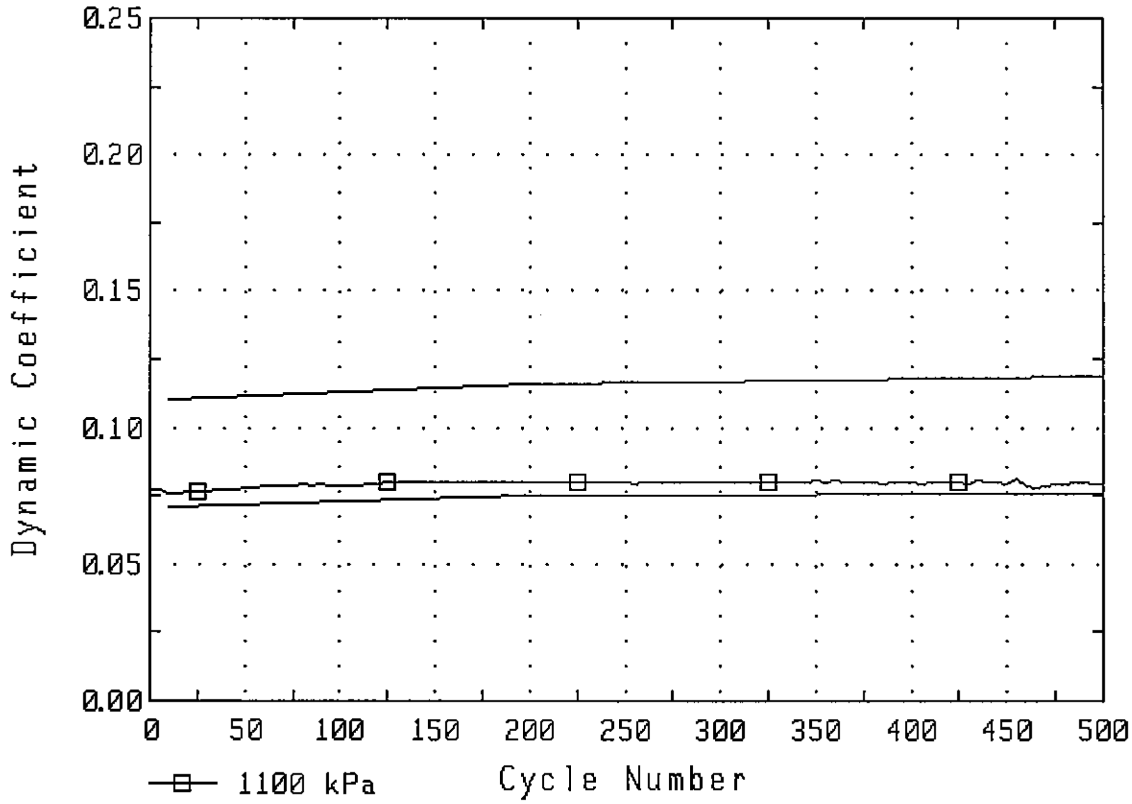
Run name & desc:	J0508211 - LO-250033
Run date:	08/31/10
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J" MACHINE LO-250033
Sequence name:	SEQ1220
Remarks:	Use 1Y0709 Disc and 8E4095 Plate
Number of cycles run:	1087

Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 $N\text{-}m\text{-}s^2$

Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	007080C800012
Remarks:	SINTERED BRONZE

Plate name & desc:	8E4095 - Steel Plate
Surface:	0.70 to 1.00 micron Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	007080C800012
Remarks:	0.85 SURFACE FINISH

Report limit name:	LIM1220 - Reference run: J0508081
Limit file generated:	08/04/10
Report format name:	REP1220 - SINTERED BRONZE

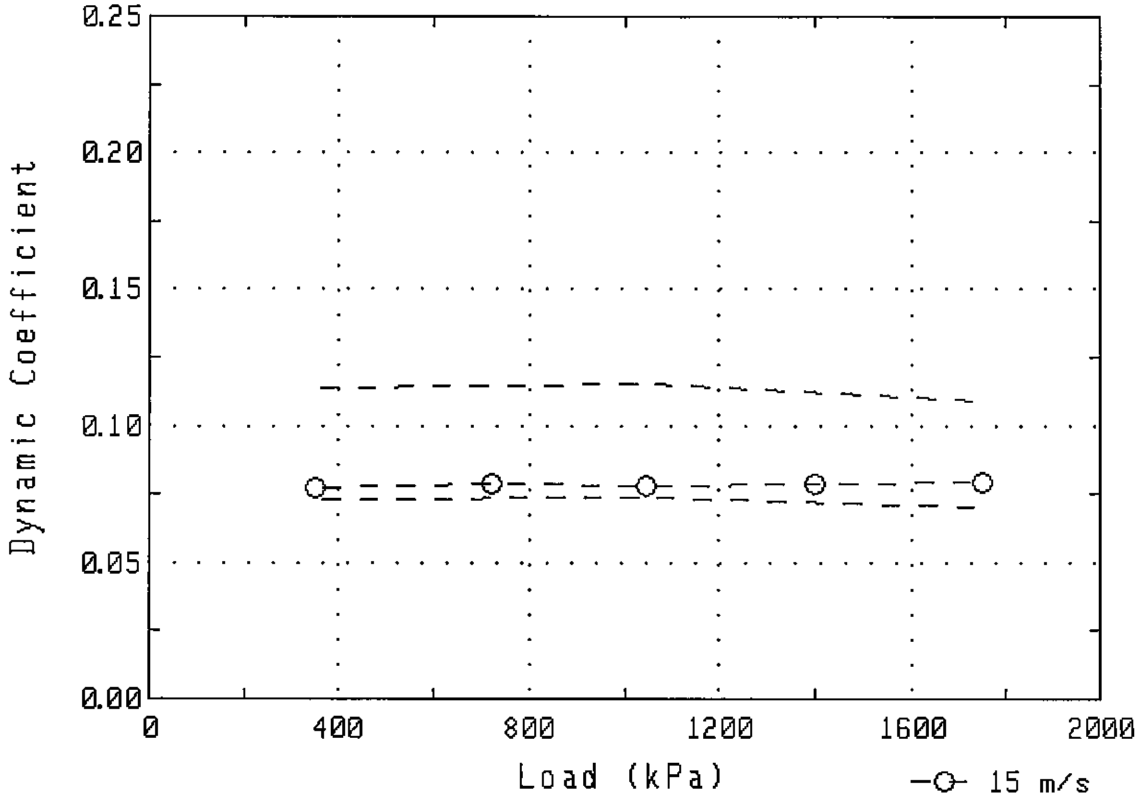


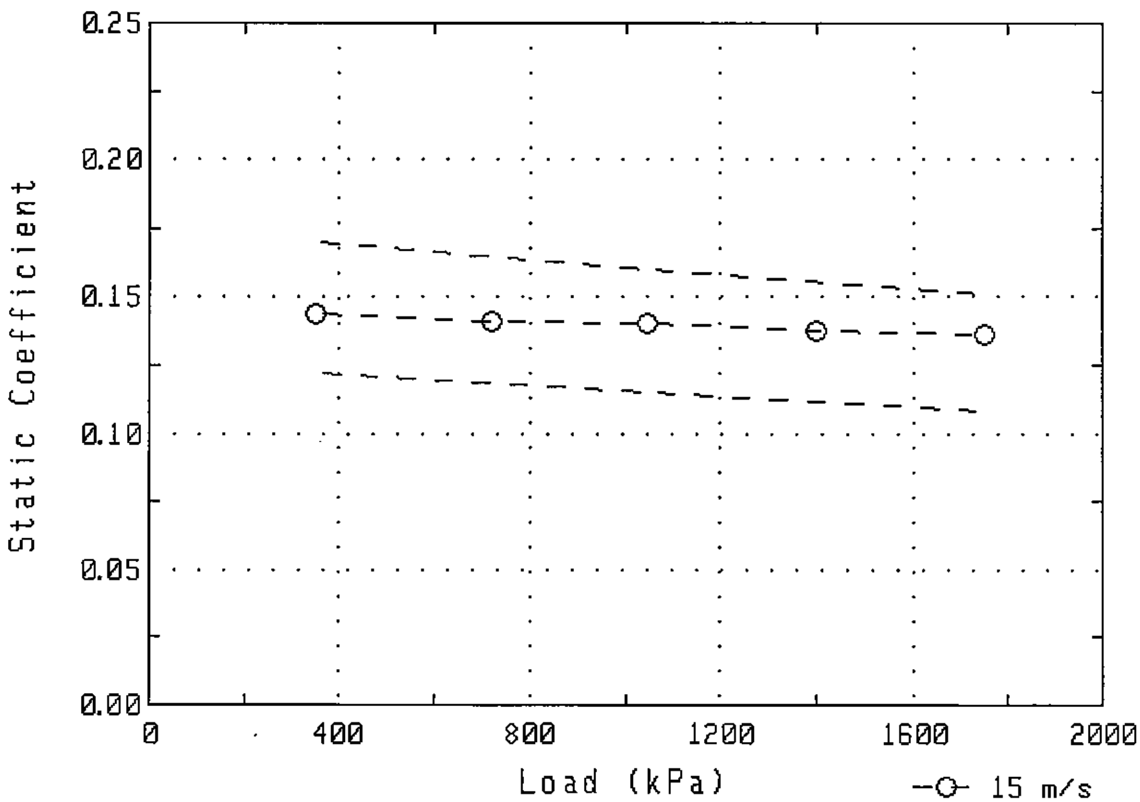
1Y0709 DISC
THICKNESS

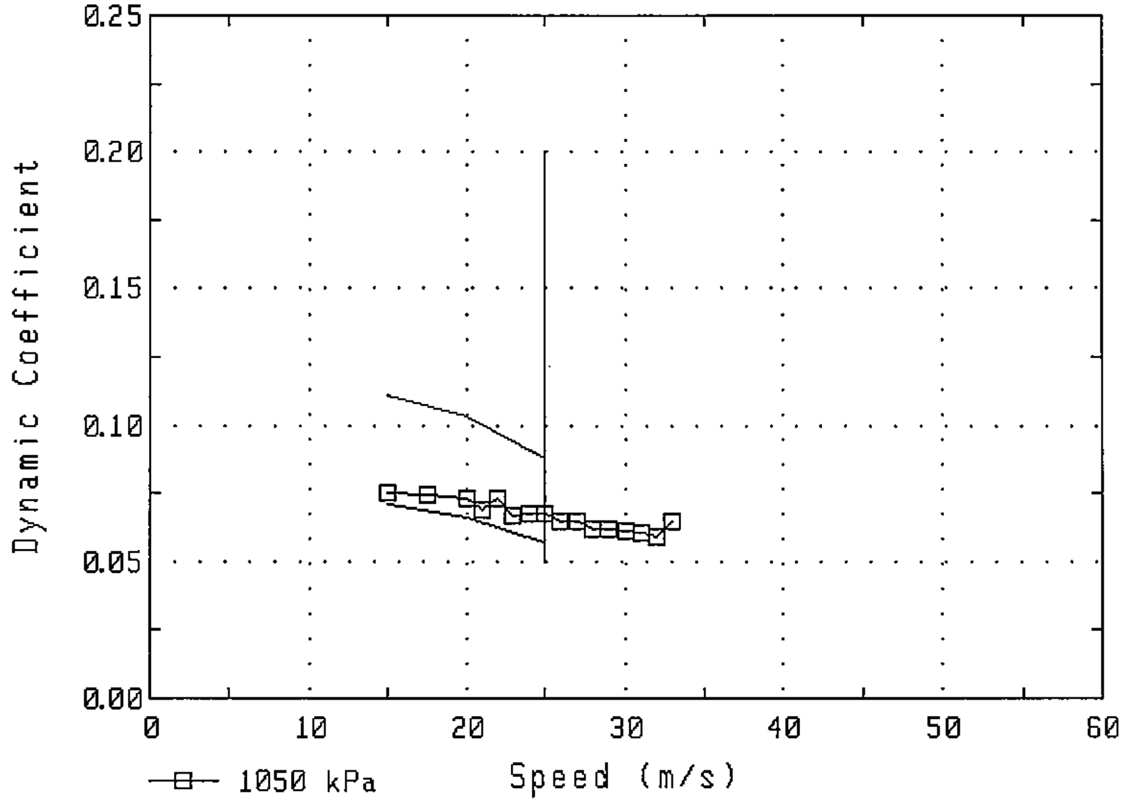
Loc	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
1	4.95	4.95	4.94	4.95	4.94	4.94
2	4.95	4.94	4.93	4.93	4.94	4.93
3	4.95	4.94	4.93	4.94	4.94	4.93
4	4.96	4.95	4.94	4.95	4.95	4.94
5	4.97	4.96	4.95	4.96	4.96	4.95
6	4.96	4.95	4.94	4.96	4.95	4.94
Avg	4.96	4.95	4.94	4.95	4.95	4.94

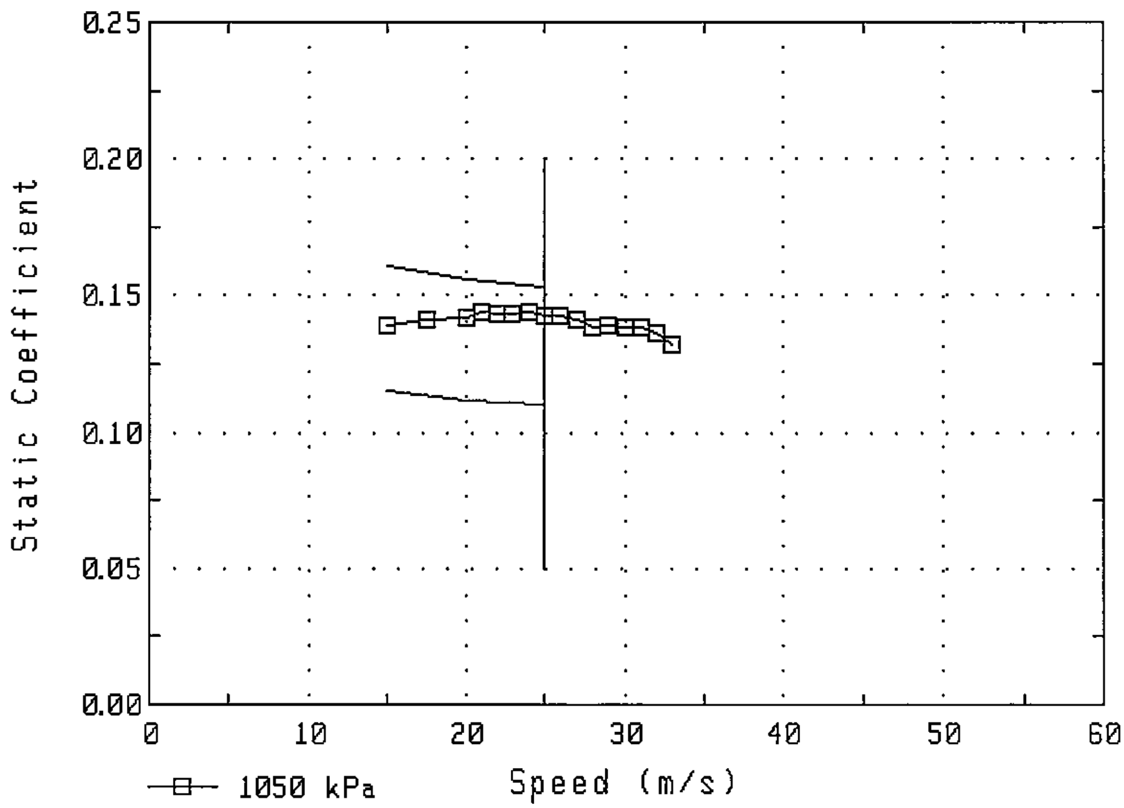
Compression set average wear: 0.005
M2 - M3 average Wear: 0.009

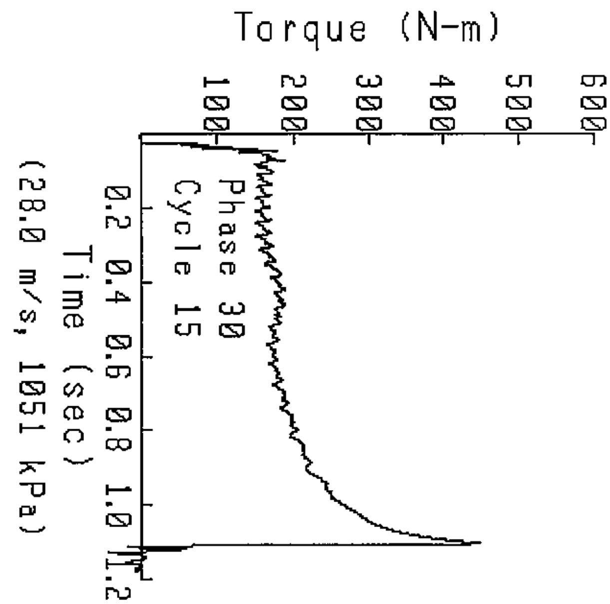
Total Wear (all measurements in mm): 0.014

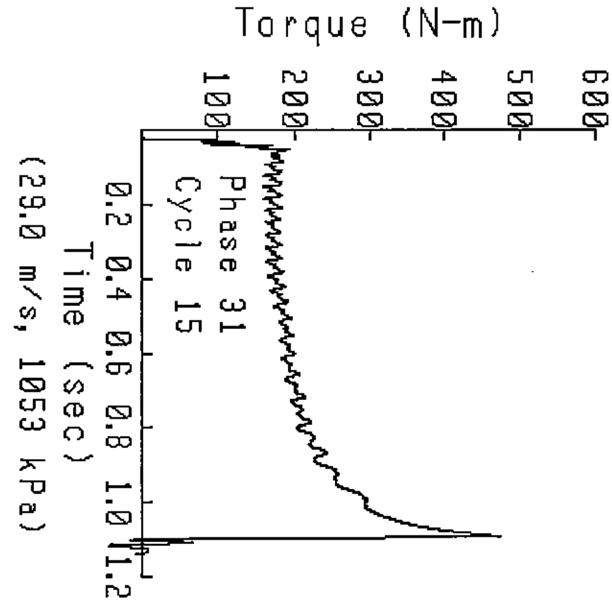

0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

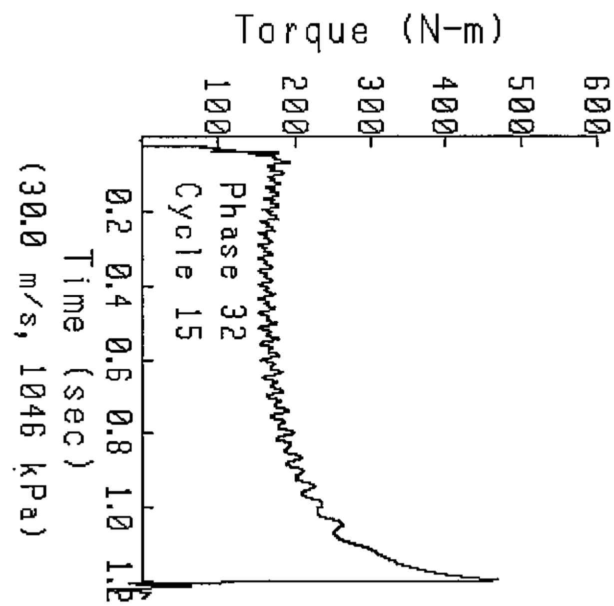

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

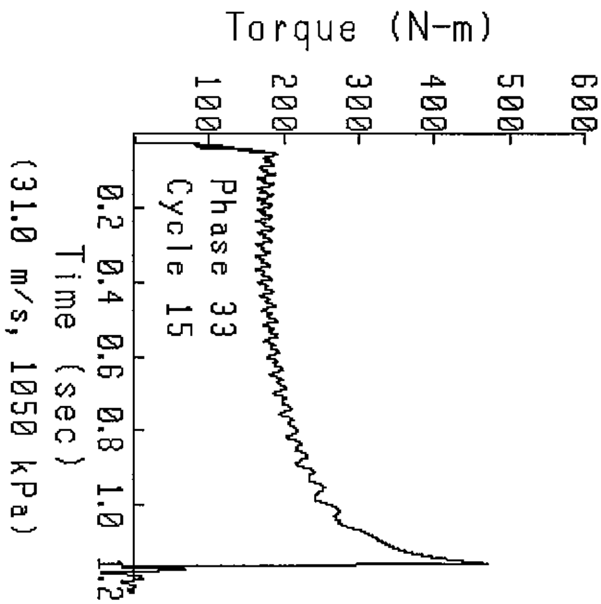

Dynamic Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

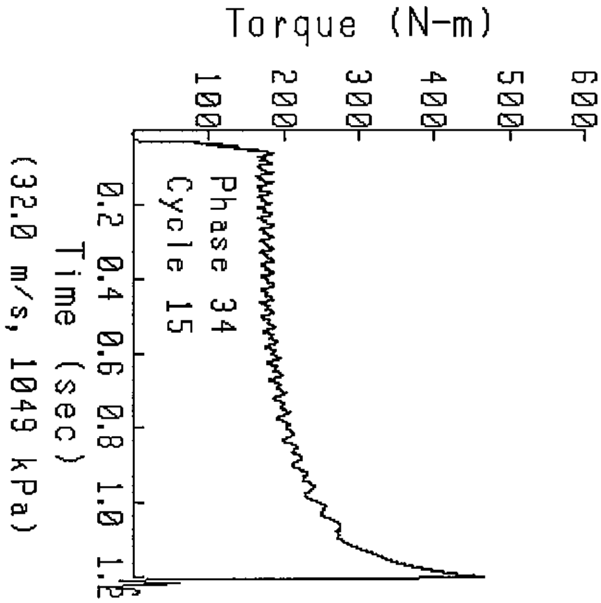

Static Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

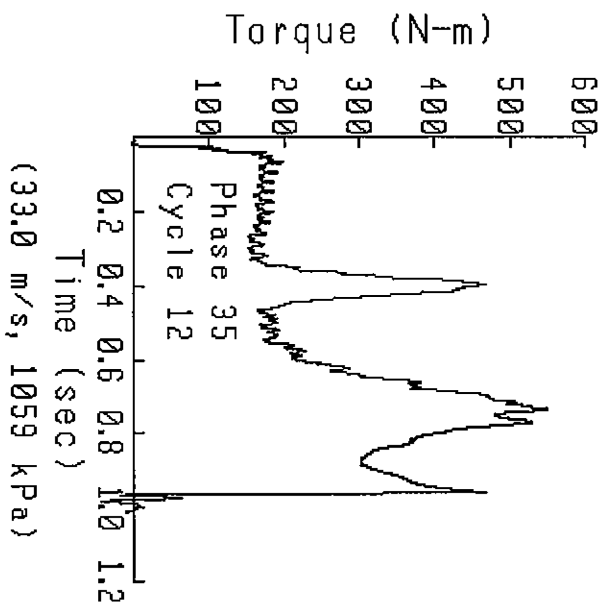

Torque (N-m)
100 200 300 400 500 600
Phase 30
Cycle 15
0.2 0.4 0.6 0.8 1.0 1.2
Time (sec)
(28.0 m/s, 1051 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 31
Cycle 15
0.2 0.4 0.6 0.8 1.0 1.2
Time (sec)
(29.0 m/s, 1053 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 32
Cycle 15
0.2 0.4 0.6 0.8 1.0 1.2
Time (sec)
(30.0 m/s, 1046 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 33
Cycle 15
0.2 0.4 0.6 0.8 1.0 1.2
Time (sec)
(31.0 m/s, 1050 kPa)

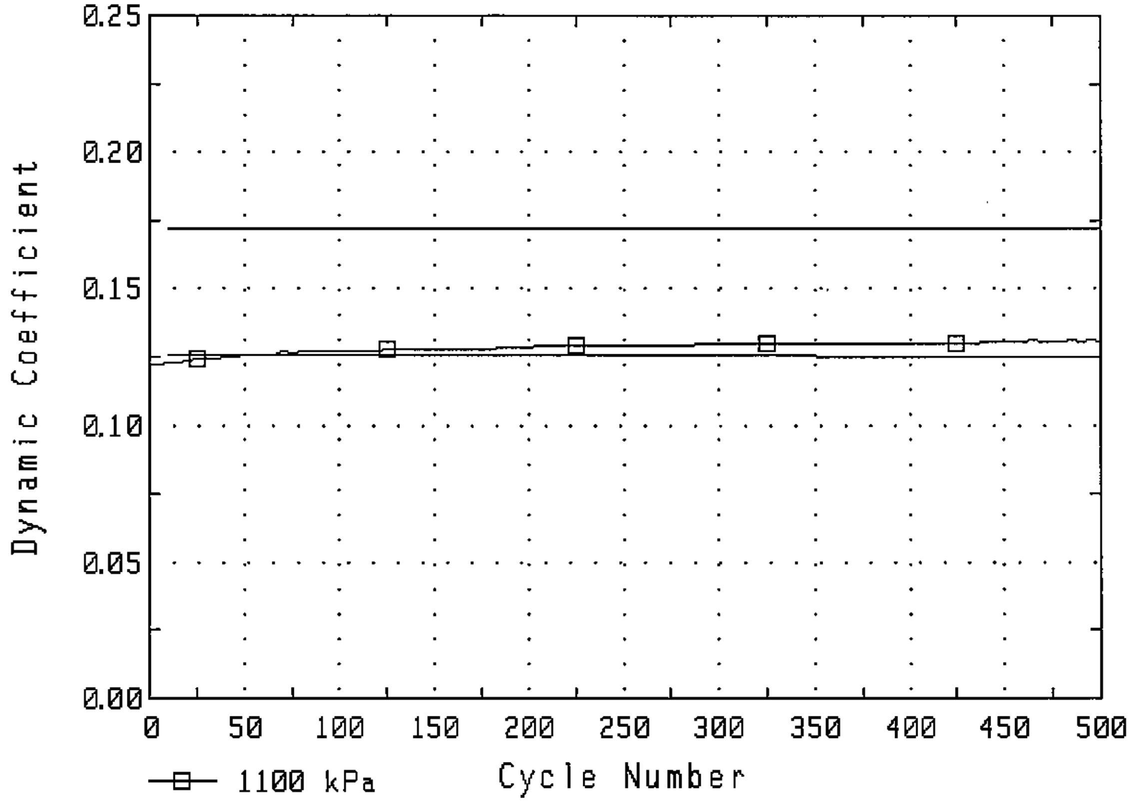

Torque (N-m)
100 200 300 400 500 600
Phase 34
Cycle 15
0.2 0.4 0.6 0.8 1.0 1.2
Time (sec)
(32.0 m/s, 1049 kPa)


Torque (N-m)
100 200 300 400 500 600
Phase 35
Cycle 12
0.2 0.4 0.6 0.8 1.0 1.2
Time (sec)
(33.0 m/s, 1059 kPa)

Southwest Research Institute
"J" MACHINE OIL TEST LO250033 / LO-250033

Test name:	A-101-J
Test date:	08/30/10
Test description:	J Machine LO250033
Oil type:	LO250033 / LO-250033
Viscosity:	5w-30
Miscellaneous:	
Software version:	1.40
Run name & desc:	J0508212 - LO250033
Run date:	09/01/10
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J" MACHINE OIL TEST LO250033 / LO-250033
Sequence name:	SEQ1222
Remarks:	Use 1Y0711 Disc and 1Y0726 Plate
Number of cycles run:	1110
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 N-m-s^2
Disc name & desc:	1Y0711 - Wheel Brake Paper
Material:	Raybestos 7902-1 Paper
Groove pattern:	2 - 37 Multiple Parallel
Miscellaneous:	Use with 1Y0726 Steel Plate
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	06MR928188
Remarks:	WHEEL BRAKE PAPER
Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	06MR928188
Remarks:	0.25 SURFACE FINISH
Report limit name:	LIM1222 - Reference run: J0508195
Limit file generated:	08/04/10
Report format name:	REP1222 - WHEEL BRAKE PAPER

Test: A-101-J Run: J0508212 Started on 09/01/10 at 07:30

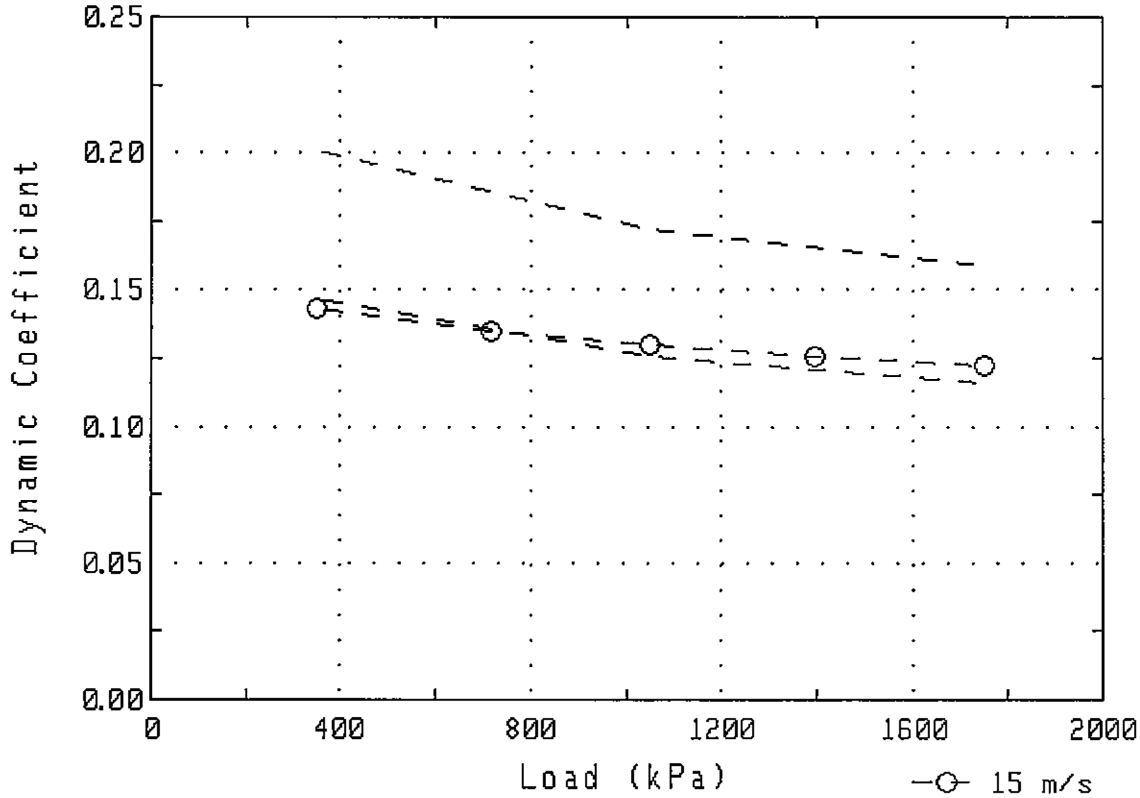


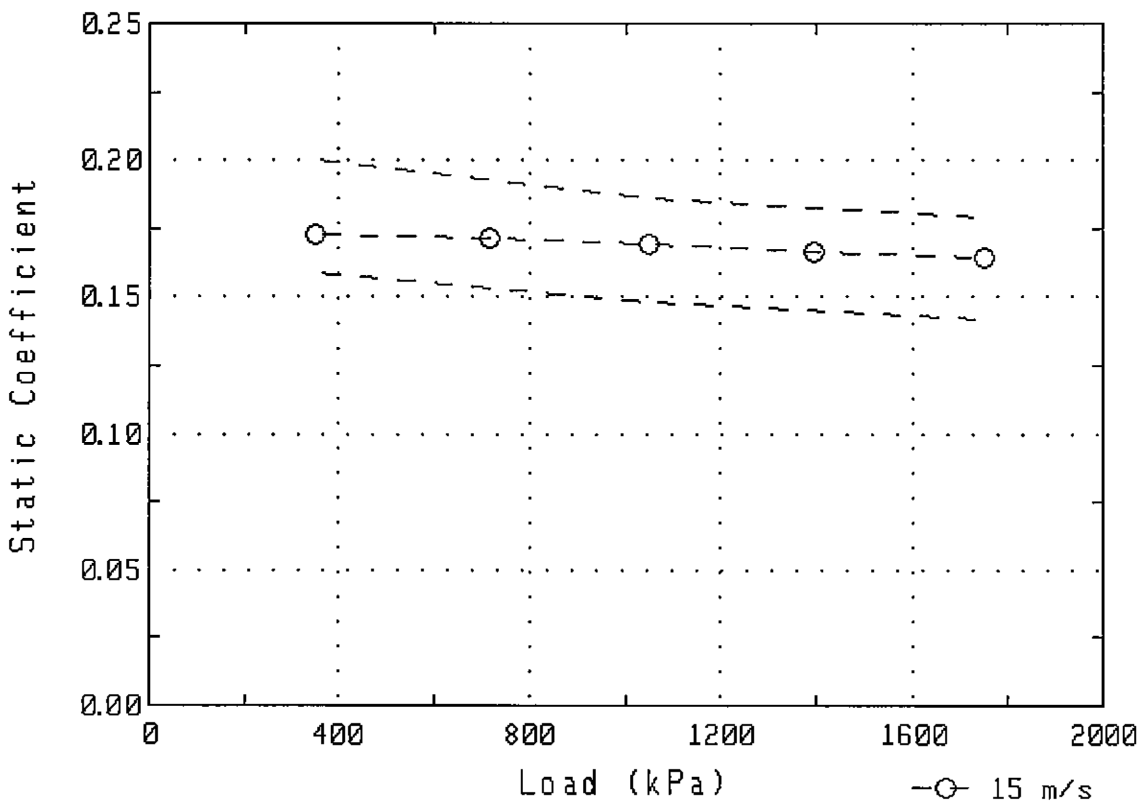
1Y0711 DISC
THICKNESS

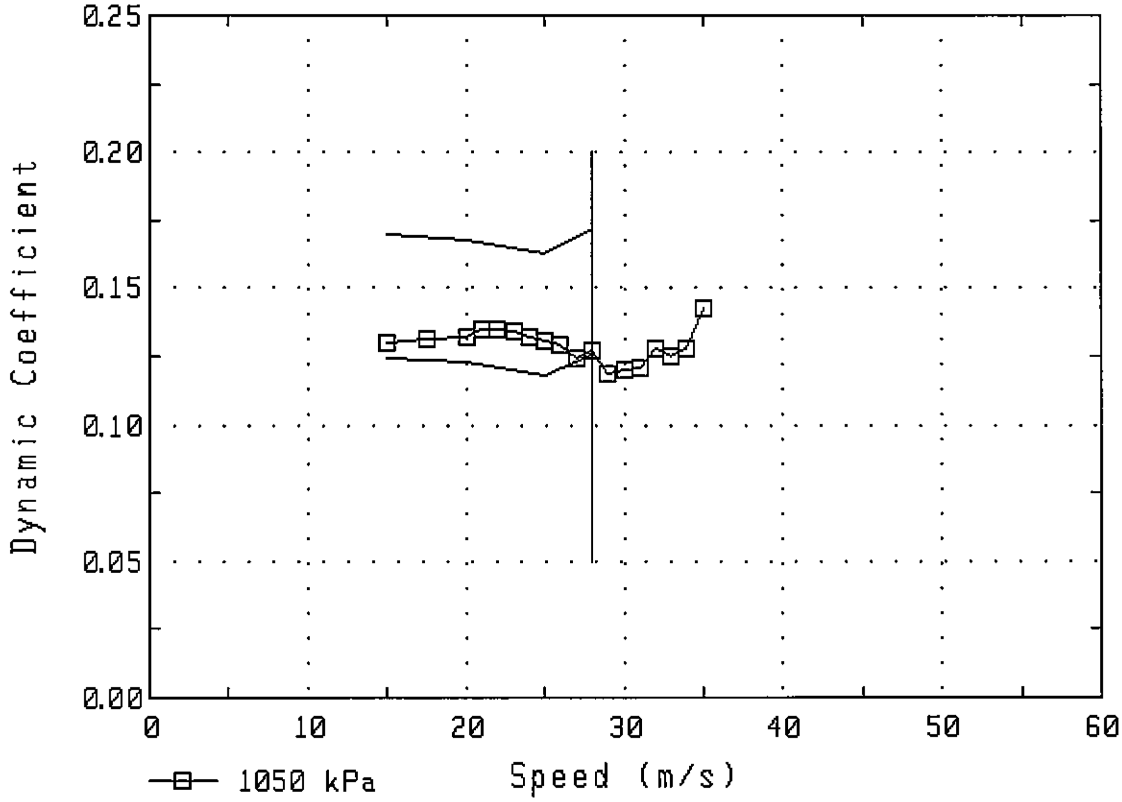
Loc	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
1	4.99	4.97	4.97	4.99	4.98	4.97
2	5.01	4.98	4.97	5.00	4.97	4.97
3	4.99	4.97	4.96	5.00	4.97	4.97
4	4.97	4.95	4.95	4.98	4.95	4.95
5	4.97	4.95	4.94	4.98	4.95	4.95
6	4.97	4.94	4.94	4.97	4.95	4.94
Avg	4.98	4.96	4.96	4.99	4.96	4.96

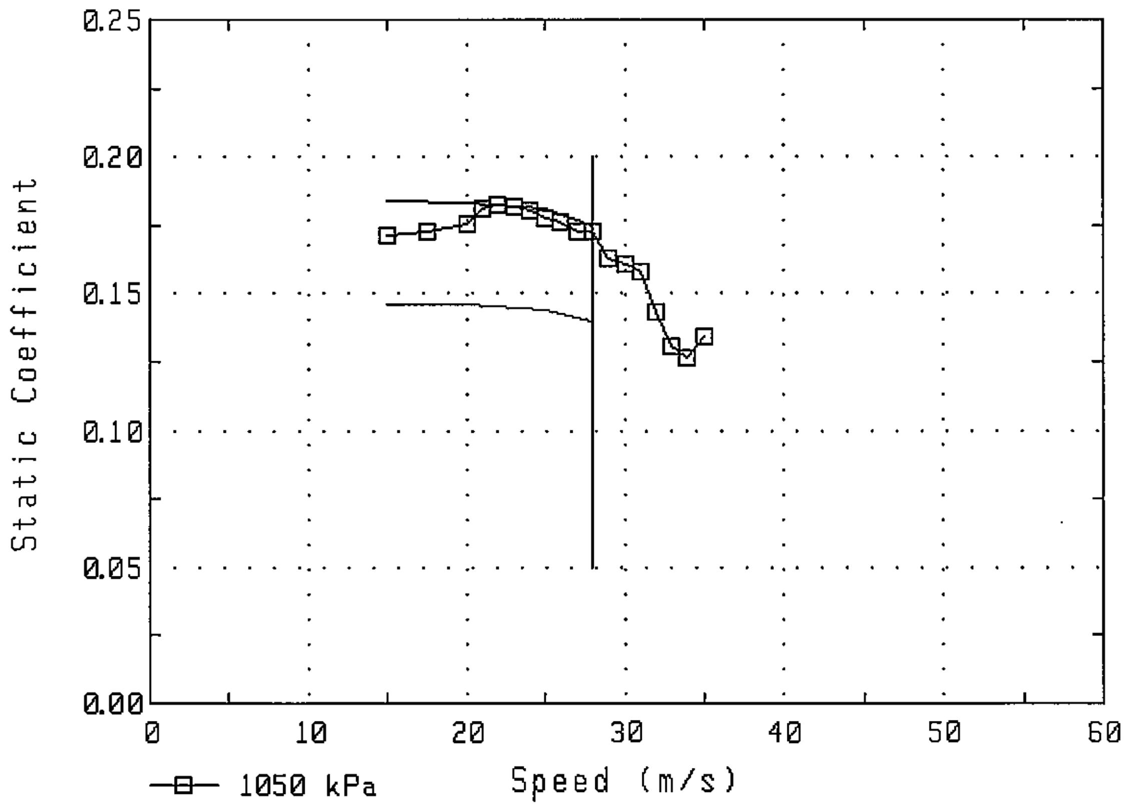
Compression set average wear: 0.024
M2 - M3 average Wear: 0.004

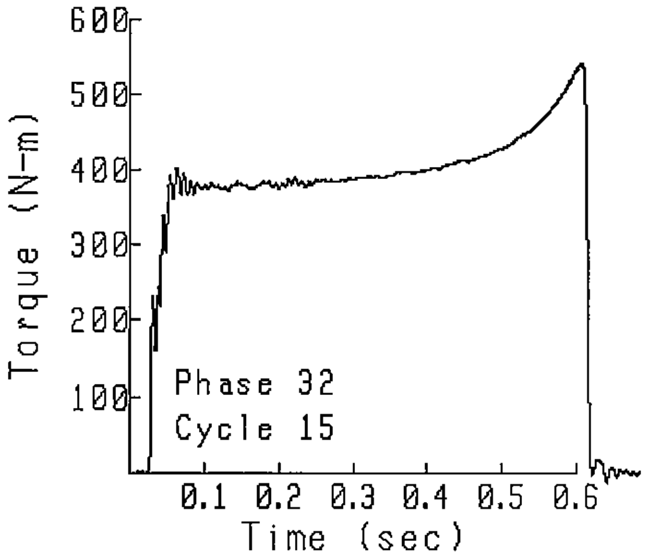
Total Wear (all measurements in mm): 0.028


Dynamic Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

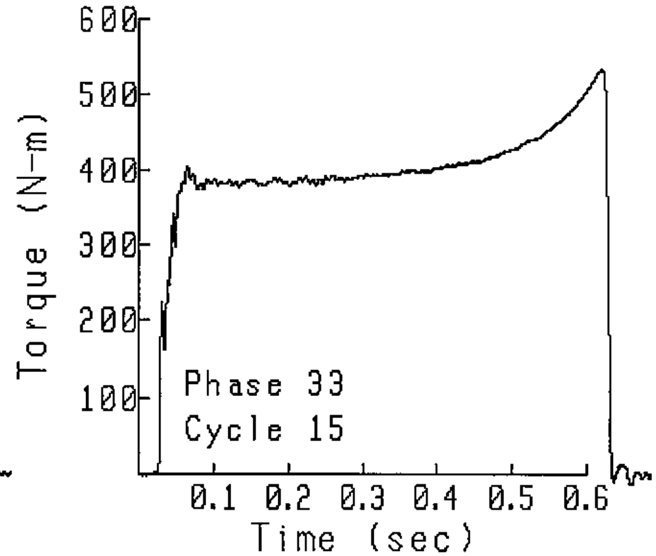

Static Coefficient
0.25
0.20
0.15
0.10
0.05
0.00
0
400
800
1200
1600
2000
Load (kPa)
15 m/s


0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

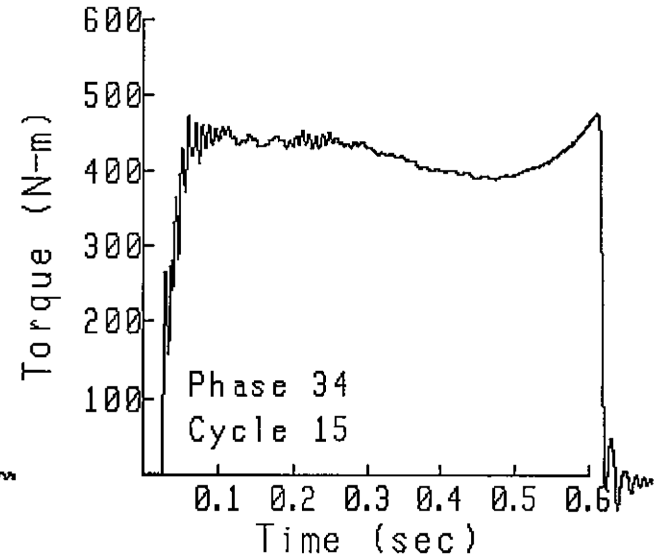

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa



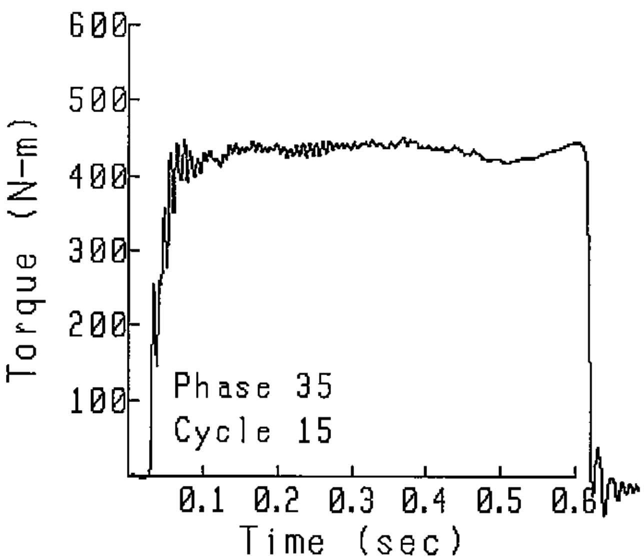
(30.0 m/s, 1050 kPa)



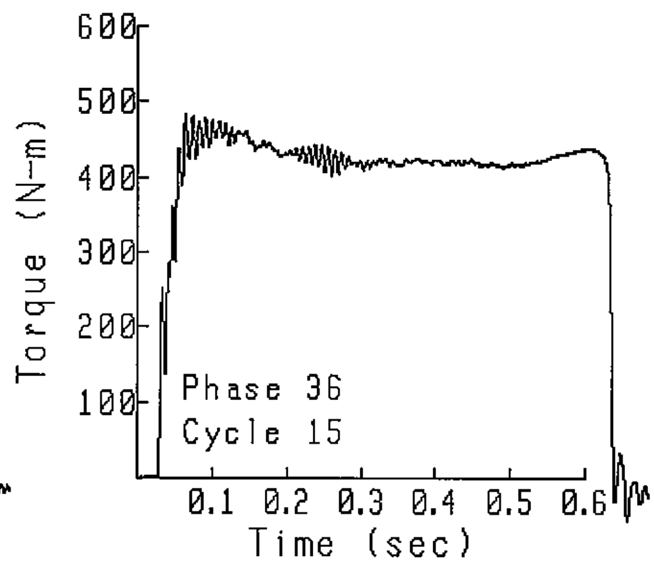
(31.0 m/s, 1051 kPa)



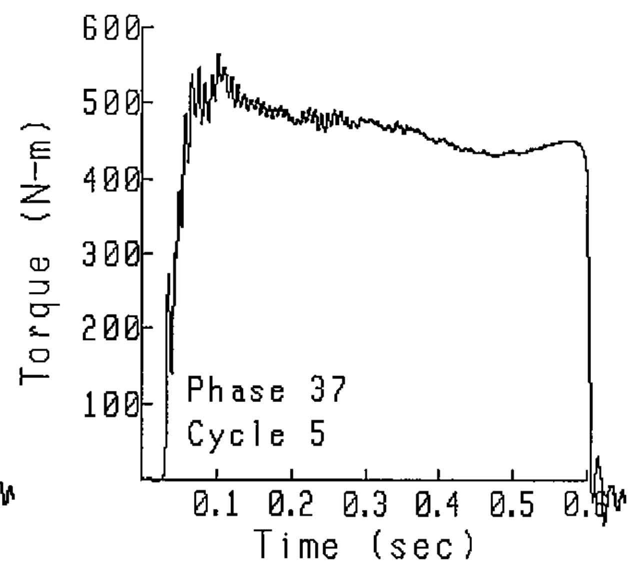
(32.0 m/s, 1046 kPa)



(33.0 m/s, 1048 kPa)



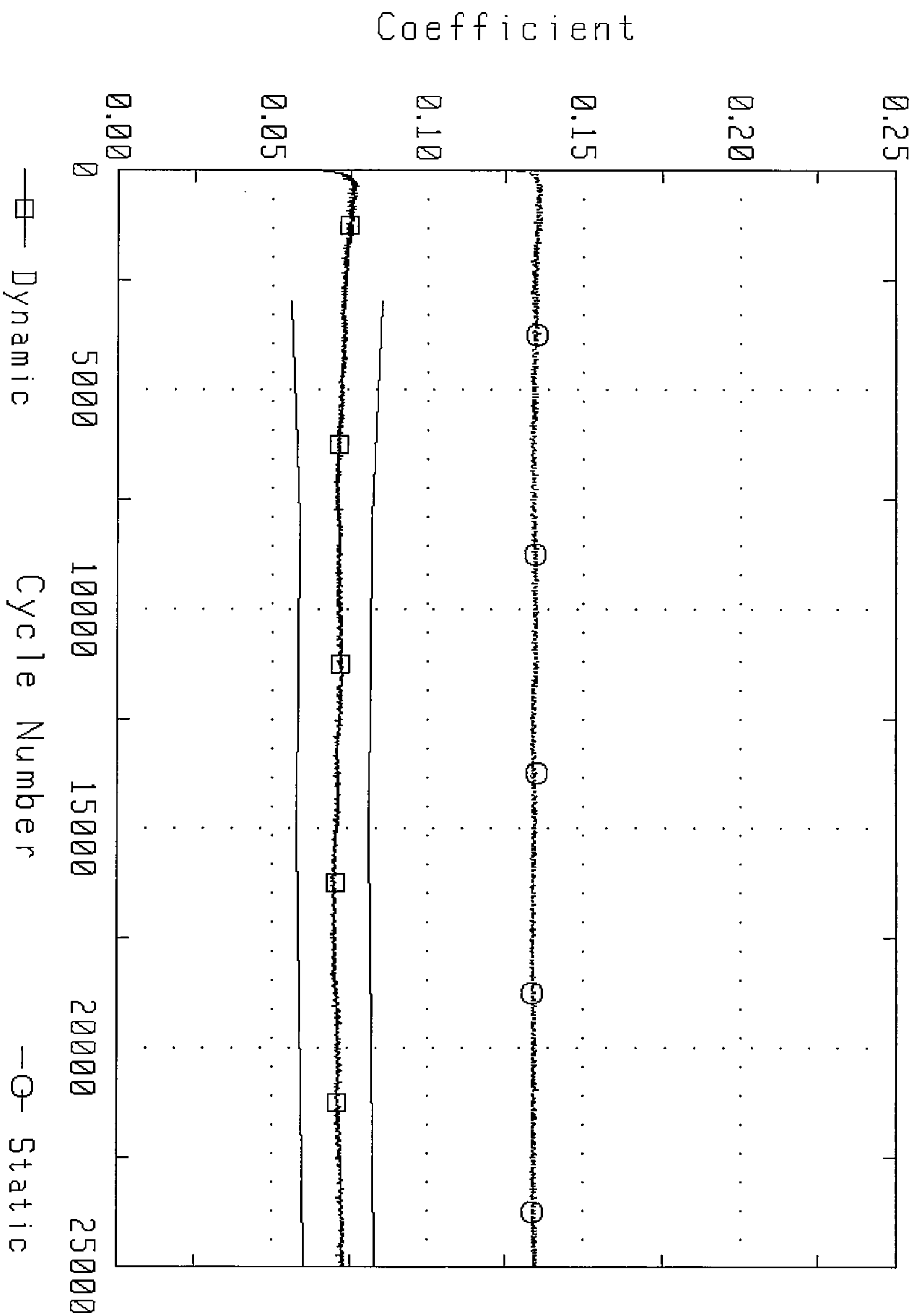
(34.0 m/s, 1049 kPa)



(35.0 m/s, 1048 kPa)

Southwest Research Institute
"J" MACHINE OIL TEST LO250033 / LO-250033

Test name:	A-101-J
Test date:	08/30/10
Test description:	J Machine LO250033
Oil type:	LO250033 / LO-250033
Viscosity:	5w-30
Miscellaneous:	
Software version:	1.40
Run name & desc:	J0508213 - LO250033
Run date:	09/02/10
Oil temperature:	115 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J" MACHINE OIL TEST LO250033 / LO-250033
Sequence name:	SEQFRRET
Remarks:	USE 1Y0709 DISC AND 1Y0726 PLATE (8E7351 GROUP)
Number of cycles run:	25100
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 N-m-s^2
Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	12FE1-00010
Remarks:	SINTERED BRONZE
Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	12FE1-00010
Remarks:	0.30 SURFACE FINISH
Report limit name:	LIMFRRET - Reference run: J0508012
Limit file generated:	08/04/10
Report format name:	REPFRRET - FRICTION RETENTION


Coefficient
0.00
0.05
0.10
0.15
0.20
0.25
0
5000
10000
15000
20000
25000
Cycle Number
Dynamic
Static

APPENDIX E4. – EVALUATION OF CANDIDATE LO251746 IN CATERPILLAR TO-4 TRANSMISSION TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Conducted for

ARMY LAB

Oil Code:
LO251746

Test Numbers:
VC70-A-102-J

September 14, 2010

Submitted by:

Brian Koehler
Principal Engineer
Specialty & Driveline Fluid Evaluations

CATERPILLAR TO-4 FRICTION PROPERTIES, VC-70

Summary Sheet

Company: ARMY LAB

Test start date: September 7, 2010
End of test date: September 14, 2010
Oil Code: LO251746

Sequence Number	1219	1220	1221	1222	1223	1224	Friction Retention
Dynamic Coefficient Vs. Cycle:		F	F				P
Dynamic Coefficient Vs. Load:		F	F				
Dynamic Coefficient Vs. Speed:		F	F				
Energy Limit:		P	P				
Static Coefficient Vs. Load:		F	F				
Static Coefficient Vs. Speed:		F	F				
Energy Limit:		P	P				
Total Wear:		0.039	0.007				
Wear Limit:	0.030	0.040	0.070	0.070	0.070	0.040	

Comments: This testing was conducted on a referenced test stand. The results are compared to TO-4 testing limits. 2009 Batch parts were used for all sequences except FRRET.

F = Fail
P = Pass
N/A = Not Applicable

SOUTHWEST RESEARCH INSTITUTE
"J" MACHINE OIL TEST LO251746 / LO-251746

Test name:	A-102-J
Test date:	09/07/10
Test description:	J MACHINE LO251746
Oil type:	LO251746 / LO-251746
Viscosity:	0W-30
Miscellaneous:	
Software version:	1.40

Run name & desc:	J0508214 - LO251746
Run date:	09/08/10
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J" MACHINE OIL TEST LO251746 / LO-251746
Sequence name:	SEQ1220
Remarks:	Use 1Y0709 Disc and 8E4095 Plate
Number of cycles run:	1083

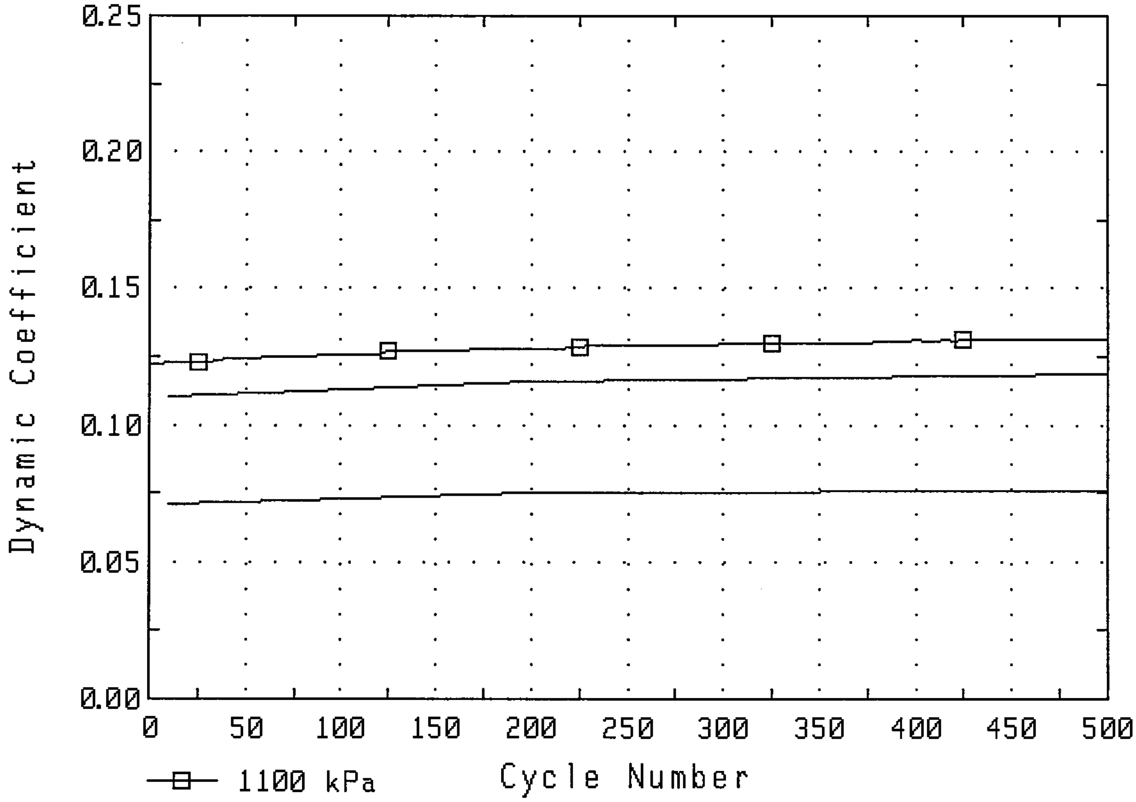
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 $N\text{-}m\text{-}s^2$

Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	007080C800012
Remarks:	SINTERED BRONZE

Plate name & desc:	8E4095 - Steel Plate
Surface:	0.70 to 1.00 micron Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	007080C800012
Remarks:	0.90 SURFACE FINISH

Report limit name:	LIM1220 - Reference run: J0508081
Limit file generated:	08/04/10
Report format name:	REP1220 - SINTERED BRONZE

Test: A-102-J Run: J0508214 Started on 09/08/10 at 07:31

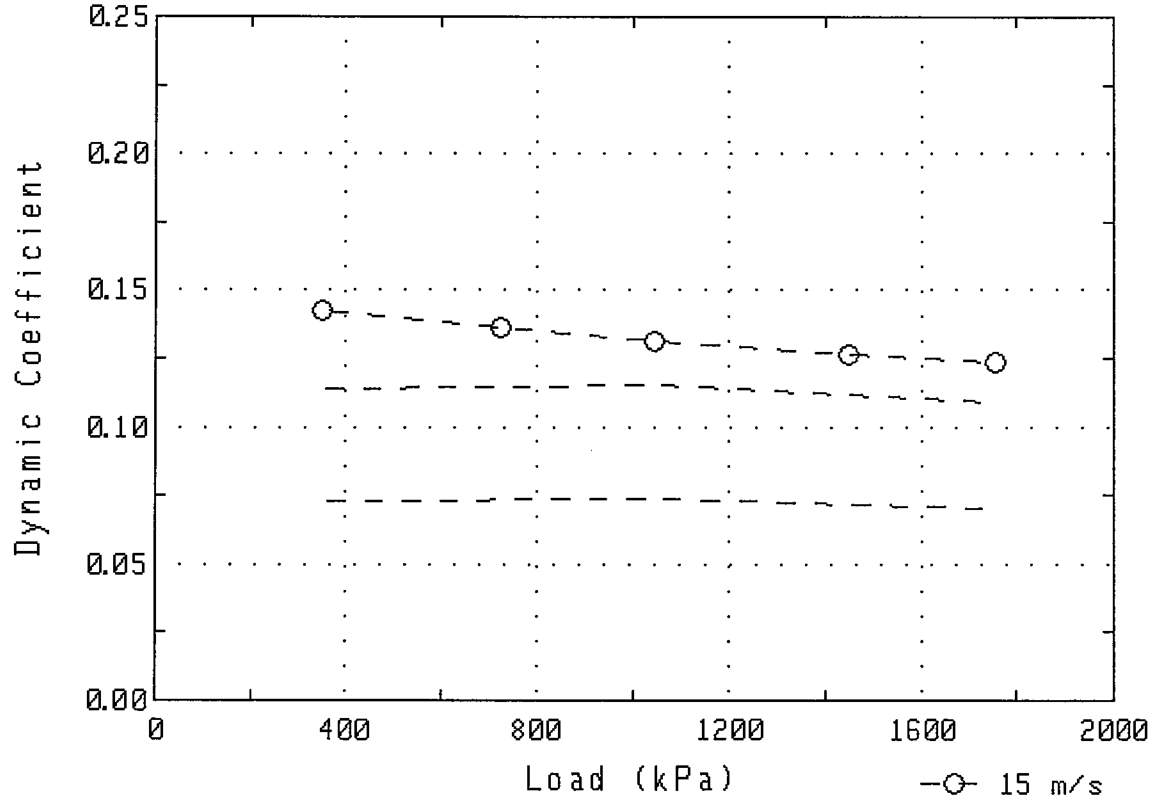


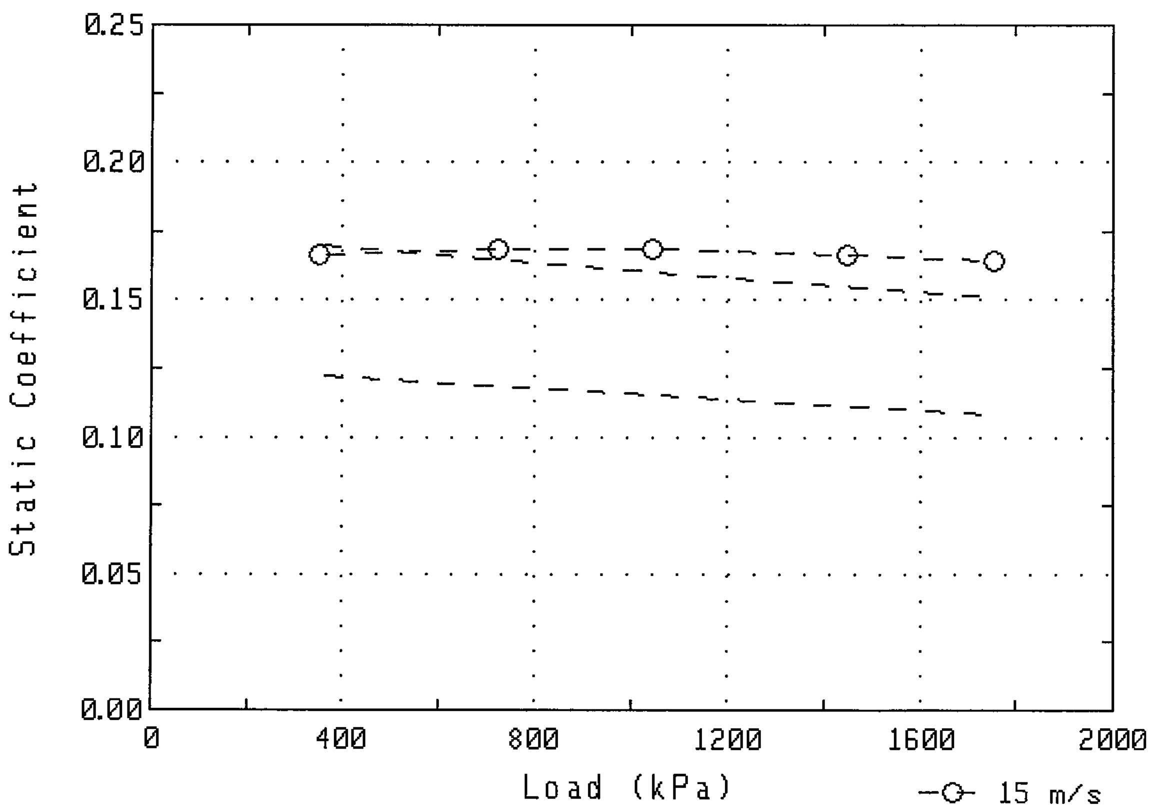
1Y0709 DISC
THICKNESS

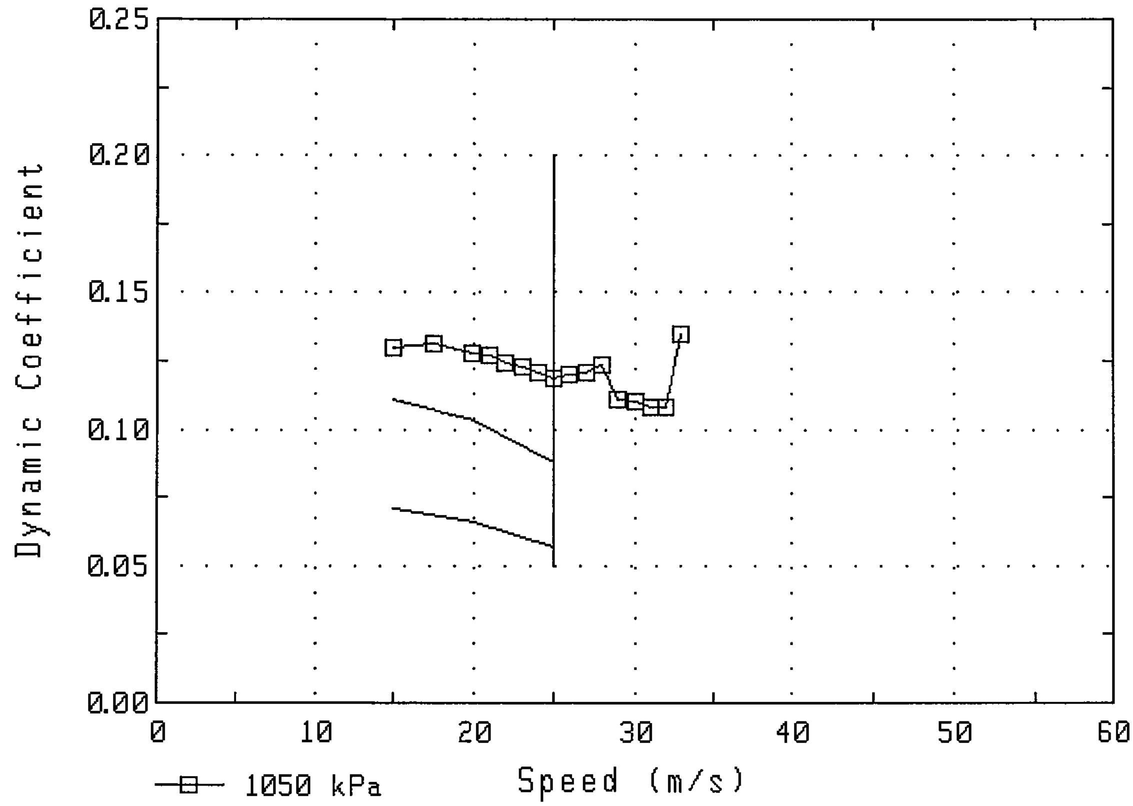
Loc	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
1	4.92	4.89	4.88	4.93	4.90	4.88
2	4.94	4.91	4.89	4.93	4.91	4.89
3	4.94	4.92	4.91	4.94	4.93	4.91
4	4.95	4.92	4.90	4.94	4.92	4.90
5	4.94	4.91	4.90	4.93	4.92	4.90
6	4.92	4.89	4.88	4.92	4.89	4.89
Avg	4.94	4.91	4.89	4.93	4.91	4.90

Compression set average wear: 0.024
M2 - M3 average Wear: 0.015

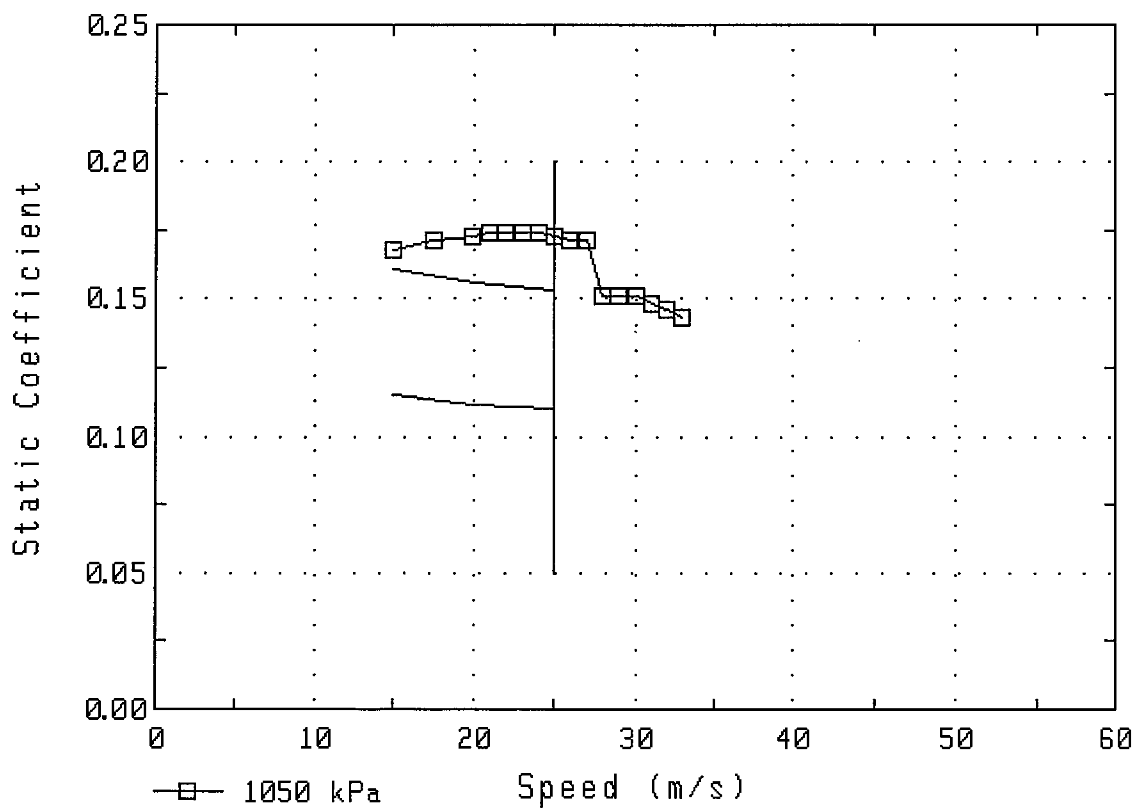
Total Wear (all measurements in mm): 0.039


0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s


0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s

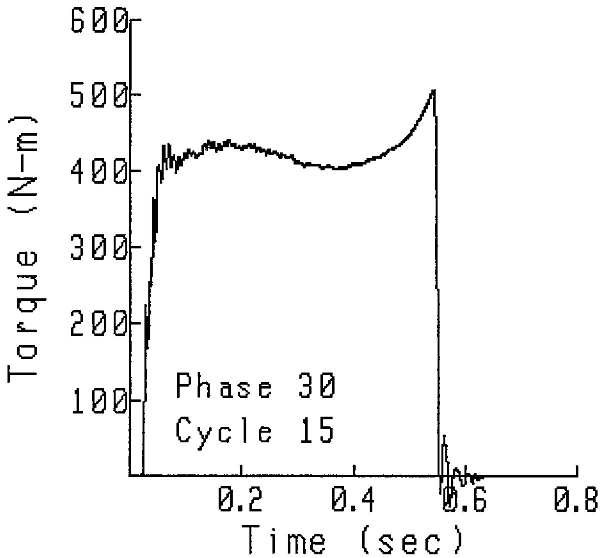


0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

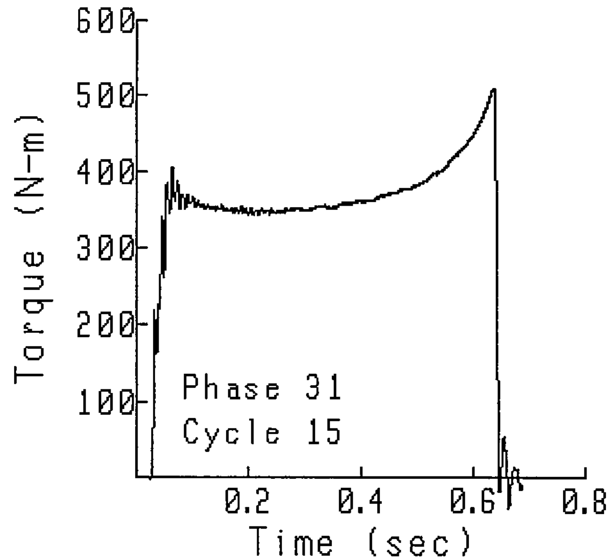


0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

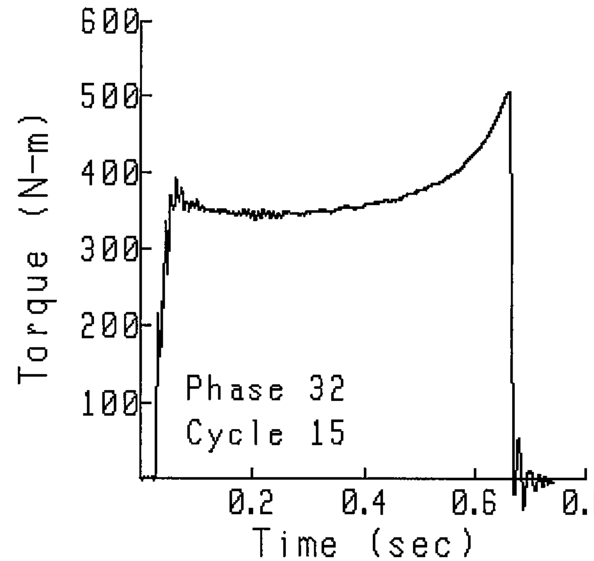
Test: A-102-J Run: J0508214 Started on 09/08/10 at 07:31



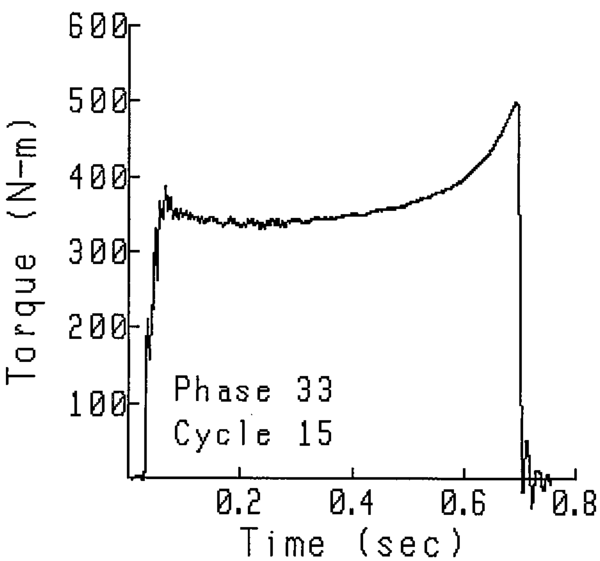
(28.0 m/s, 1051 kPa)



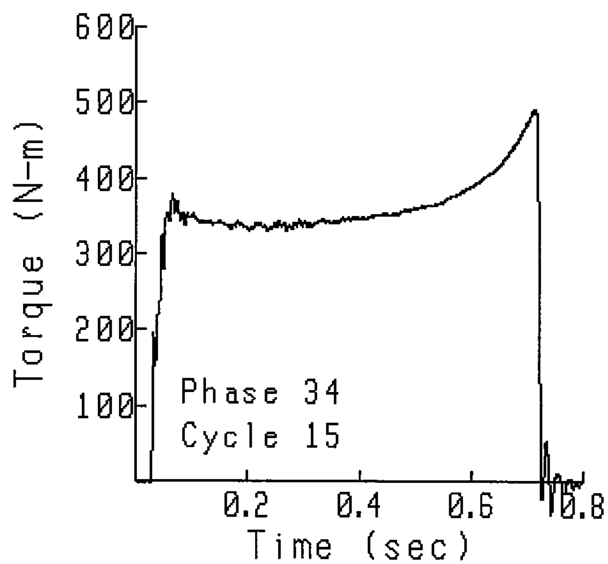
(29.0 m/s, 1048 kPa)



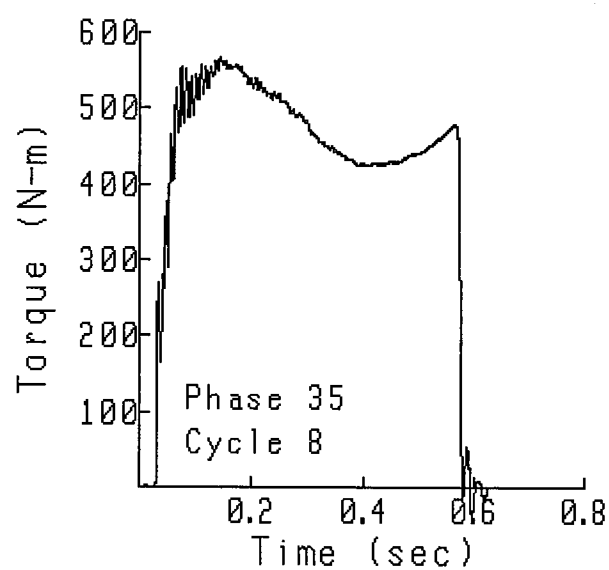
(30.0 m/s, 1049 kPa)



(31.0 m/s, 1049 kPa)



(32.0 m/s, 1048 kPa)



(33.0 m/s, 1049 kPa)

Test name:	A-102-J
Test date:	09/07/10
Test description:	J MACHINE LO251746
Oil type:	LO251746 / LO-251746
Viscosity:	0W-30
Miscellaneous:	
Software version:	1.40

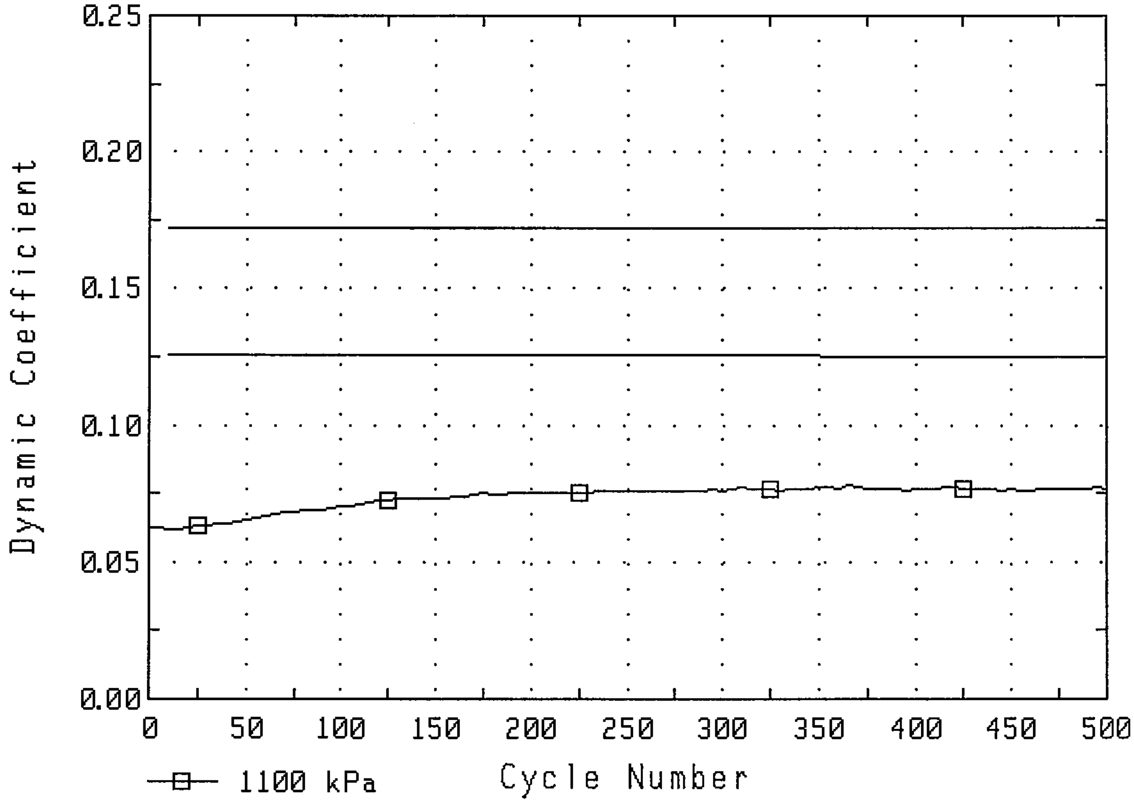
Run name & desc:	J0508215 - LO251746
Run date:	09/09/10
Oil temperature:	82 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J" MACHINE OIL TEST LO251746 / LO-251746
Sequence name:	SEQ1222
Remarks:	Use 1Y0711 Disc and 1Y0726 Plate
Number of cycles run:	1035

Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 $N\text{-}m\text{-}s^2$

Disc name & desc:	1Y0711 - Wheel Brake Paper
Material:	Raybestos 7902-1 Paper
Groove pattern:	2 - 37 Multiple Parallel
Miscellaneous:	Use with 1Y0726 Steel Plate
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	06MR928188
Remarks:	WHEEL BRAKE PAPER

Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	06MR928188
Remarks:	0.28 SURFACE FINISH

Report limit name:	LIM1222 - Reference run: J0508195
Limit file generated:	08/04/10
Report format name:	REP1222 - WHEEL BRAKE PAPER

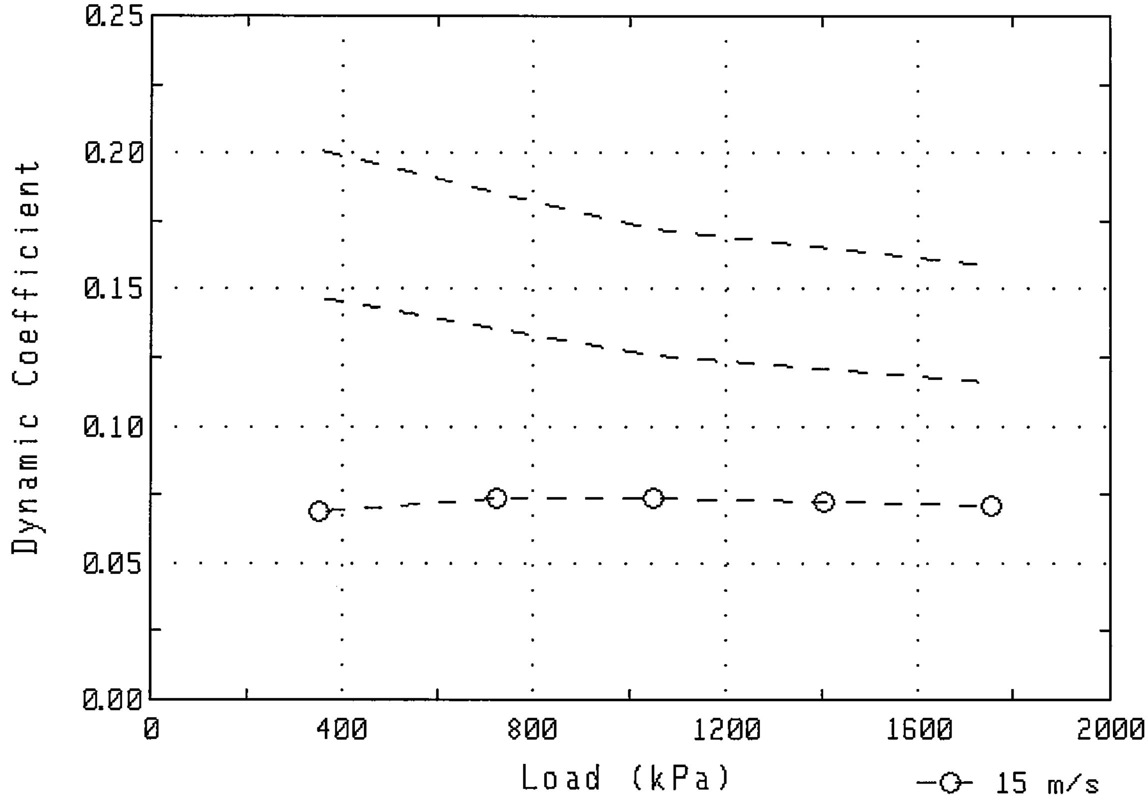


1Y0711 DISC
THICKNESS

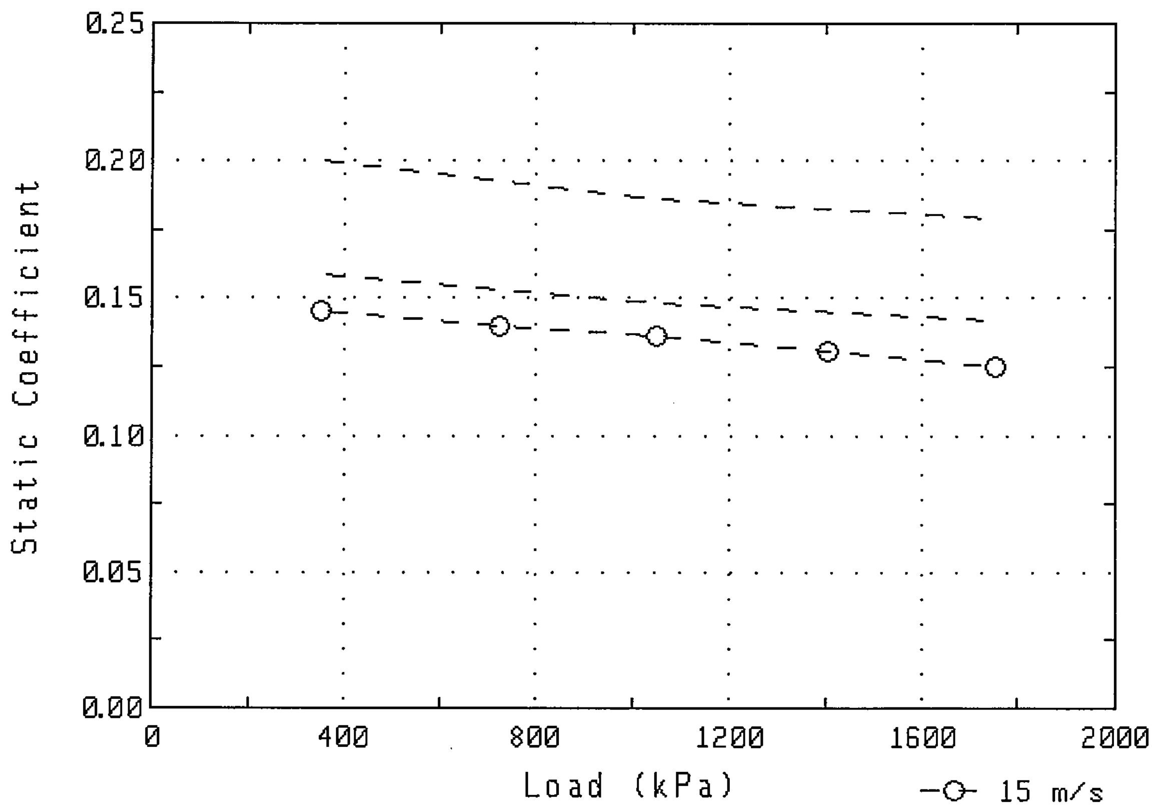
Loc	Outer Diameter M1	Outer Diameter M2	Outer Diameter M3	Inner Diameter M1	Inner Diameter M2	Inner Diameter M3
1	4.97	4.96	4.95	4.96	4.96	4.96
2	4.97	4.97	4.96	4.96	4.96	4.96
3	4.97	4.96	4.96	4.96	4.96	4.96
4	4.96	4.96	4.95	4.96	4.96	4.95
5	4.96	4.96	4.96	4.96	4.96	4.96
6	4.97	4.96	4.95	4.96	4.96	4.95
Avg	4.97	4.96	4.96	4.96	4.96	4.96

Compression set average wear: 0.003
M2 - M3 average Wear: 0.005

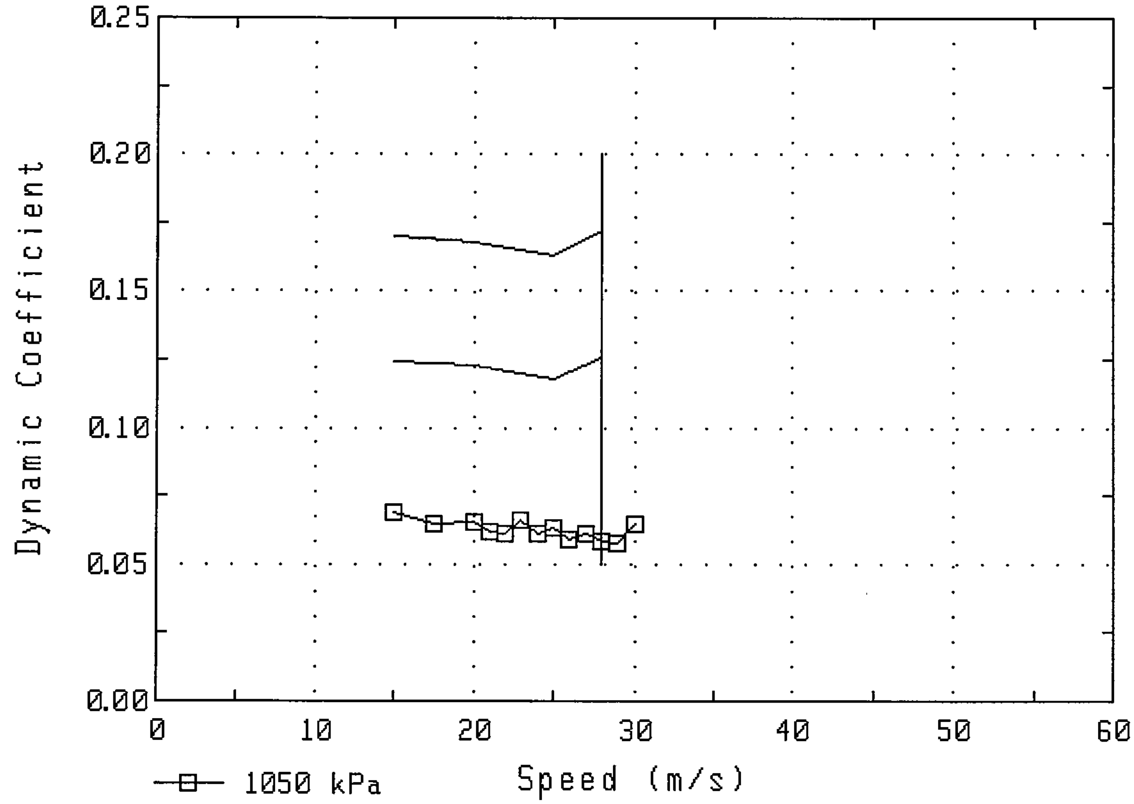
Total Wear (all measurements in mm): 0.007

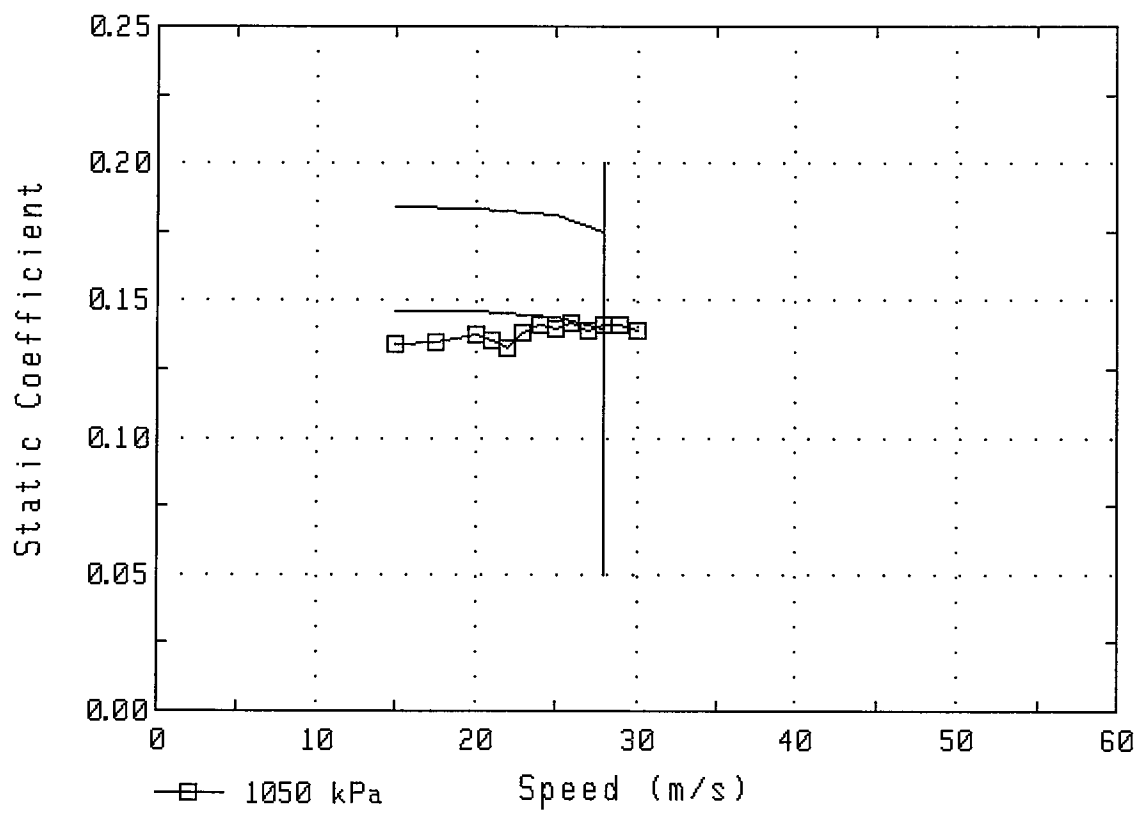


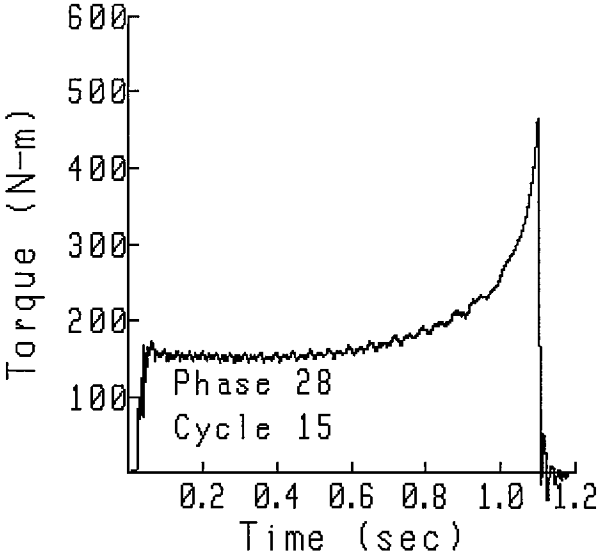
0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s



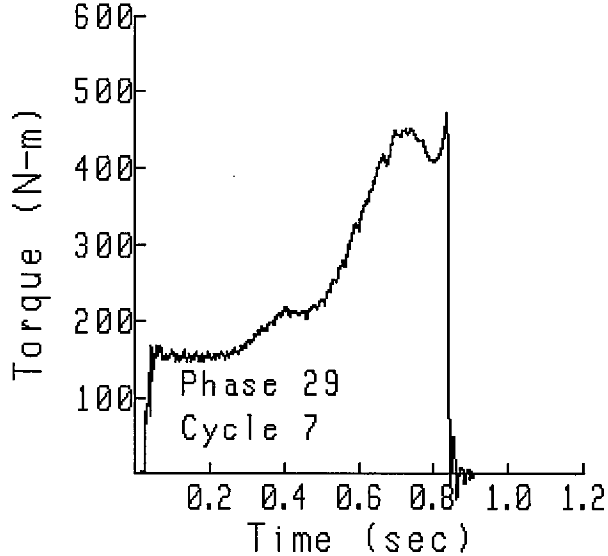
0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
400
800
1200
1600
2000
Load (kPa)
15 m/s


0.25
0.20
0.15
0.10
0.05
0.00
Dynamic Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa

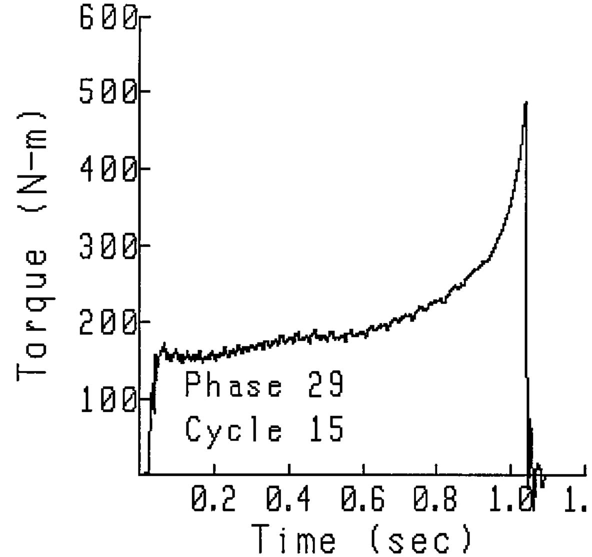

0.25
0.20
0.15
0.10
0.05
0.00
Static Coefficient
0
10
20
30
40
50
60
Speed (m/s)
1050 kPa



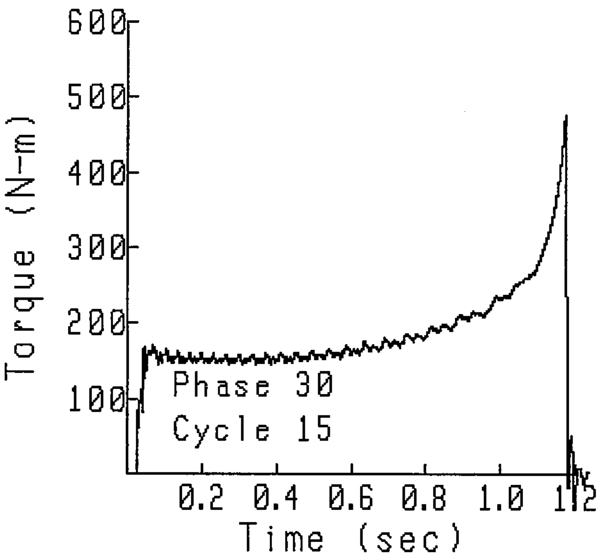
(25.9 m/s, 1020 kPa)



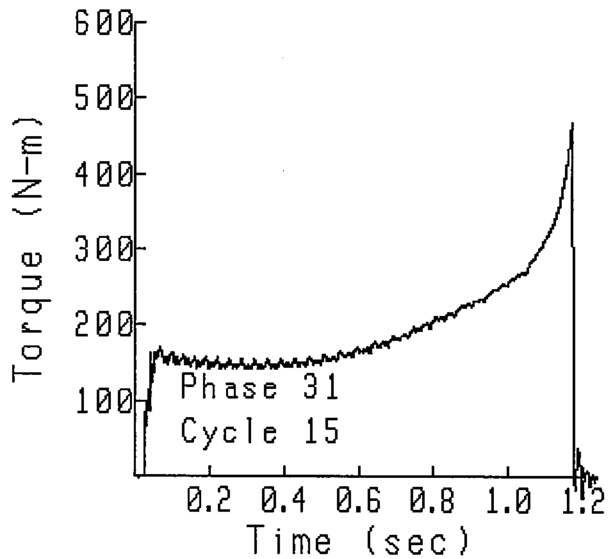
(27.0 m/s, 1059 kPa)



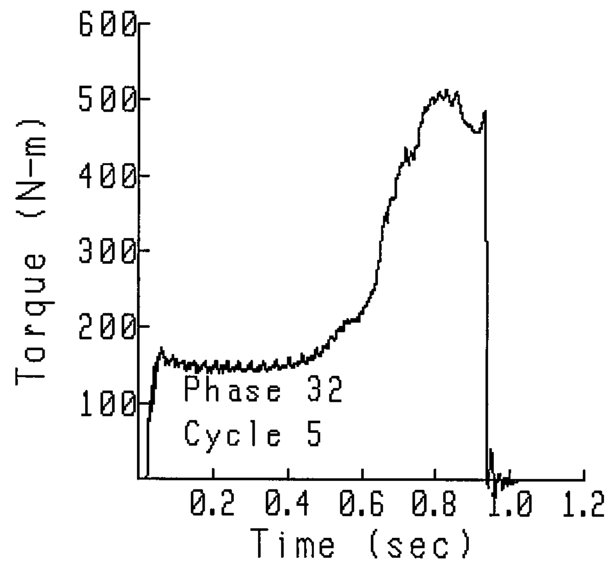
(27.0 m/s, 1049 kPa)



(28.0 m/s, 1049 kPa)

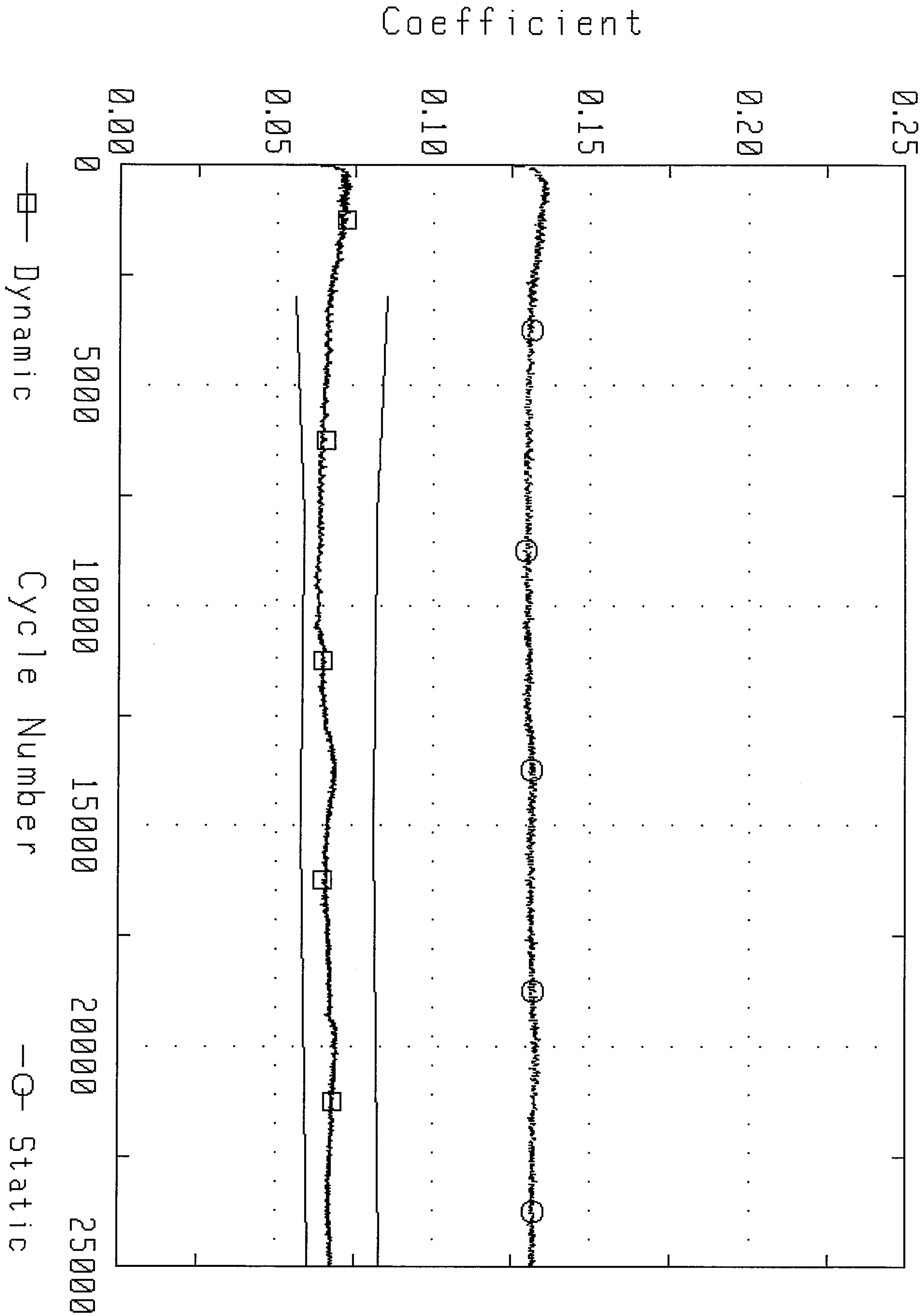


(29.0 m/s, 1053 kPa)



(30.0 m/s, 1057 kPa)

Test name:	A-102-J
Test date:	09/07/10
Test description:	J MACHINE LO251746
Oil type:	LO251746 / LO-251746
Viscosity:	0W-30
Miscellaneous:	
Software version:	1.40
Run name & desc:	J0508216 - LO251746
Run date:	09/10/10
Oil temperature:	115 degrees C
Oil flow rate:	3.78 liter/minute
Operator:	HC
Remarks:	"J"MACHINE OIL TEST LO251746 / LO-251746
Sequence name:	SEQFRRET
Remarks:	USE 1Y0709 DISC AND 1Y0726 PLATE (8E7351 GROUP)
Number of cycles run:	25100
Machine:	J
Coast down check run:	02/01/00
Result:	71.40 seconds
Inertia check run:	02/01/00
Result:	1.0349 N-m-s²
Disc name & desc:	1Y0709 - Sintered Bronze
Material:	Raybestos 1349-ET Bronze
Groove pattern:	Single Lead Spiral - 12 Radial
Miscellaneous:	Use with 8E4095 Steel Plate for performance run
Outer diameter (mm):	285.80
Inner diameter (mm):	223.20
Mean radius (mm):	128.21
Batch number:	12FE1-00010
Remarks:	SINTERED BRONZE
Plate name & desc:	1Y0726 - Steel Plate
Surface:	0.30 micron Maximum Roughness
Miscellaneous:	Install the side marked with the average roughness
Batch number:	12FE1-00010
Remarks:	0.26 SURFACE FINISH
Report limit name:	LIMFRRET - Reference run: J0508012
Limit file generated:	09/16/10
Report format name:	REPFRRET - FRICTION RETENTION


Coefficient
0.00
0.05
0.10
0.15
0.20
0.25
0
5000
10000
15000
20000
25000
Cycle Number
Dynamic
Static

APPENDIX F1. – EVALUATION OF CANDIDATE LO253071 IN JOHN DEERE JDQ-96 WET BRAKE TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

John Deere JDQ-96
Performed using 1400 Series Axle

Conducted for

U.S. ARMY TARDEC

LO253071

Test Number
10979

August 2, 2010

Submitted by:

Michael D. Lochte
Director
Specialty & Driveline Fluids
Evaluations

John Deere JDQ-96 Performed using 1400 Series Axle

General Information

Oil Code: LO253071	E.O.T. Date: August 2, 2010

Purpose

The purpose of this test was to evaluate the anti-chatter properties of this oil on the brakes of a 1400 series John Deere Inboard Planetary Axle.

Test Procedure

The test was performed as specified by John Deere Product Engineering. The only changes made to the Deere procedure were those necessary to compensate for a different spiral bevel gear ratio. This procedure is proprietary to Deere and Company.

Data Interpretation

The capacity for each engagement is the average torque during the middle of the engagement. The torque variation is the greatest difference between the maximum and minimum torque recorded during any 0.2-second portion of the engagement. The SwRI variation is the sum of all differences between the maximum torque and minimum torque for each engagement. It is obtained by summing all torque variations of each 0.2-second time block of all engagements.

Test Number

The run number listed on this report is a random number and is not sequential. Only SwRI® can link this run number to JDQ-96, LO253071, August 2, 2010.

John Deere JDQ-96 Performed using 1400 Series Axle

Results

Oil Code: LO253071	**E.O.T. Date:** August 2, 2010

The candidate results can be compared to the baseline reference average. Pass or fail decisions are only made by John Deere Product Engineering. The current reference baseline average is the average of the five most recent tests.

Current Reference Baseline Average (N · m)					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	342,372	342,248	342,379	341,574	1,368,573
Torque Variation	93,746	85,882	85,732	89,992	355,352

Results From Test Candidate LO253071					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	360,738	---	---	---	360,738
Torque Variation	164,190**	---	---	---	164,190

* This test was run for 1,000 cycles per customer's request.
** This oil created high levels of brake noise.

Table 1 of the Appendix contains chatter test results from 1,000 cycles. Table 6 contains results of the five current baseline reference tests. Figures 1 through 4 are graphic presentations of candidate oil performance compared to baseline reference data.

Table 7 contains the results of the 1000-cycle reference test that was conducted before the test on LO253071. Figure 5 is a graphic presentation of 1000-cycle reference results on LO253071. Table 8 contains the history of tests conducted on reference oil.

John Deere JDQ-96 Performed using 1400 Series Axle

Oil Code: LO253071	E.O.T. Date: August 2, 2010

Appendix

Tables

August 2, 2010

TABLE 1: JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES

SwRI Oil Code LO-253071 Sponsor Oil Code LO253071

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	3996	4330	27	4546	1550	50	4607	1500	59	4549	1520	71
10	3831	4435	4030	27	4511	1750	50	4532	1790	59	4424	1810	71
15	3831	4128	2940	27	4447	1880	49	4454	1990	59	4382	2040	71
20	3831	4229	1760	27	4368	1760	49	4317	1950	59	4335	2010	71
25	3831	4266	1600	27	4296	1950	50	4280	2000	60	4245	2080	72
30	3831	4202	1580	28	4216	1900	50	4201	2000	61	4185	2120	72
35	3831	4124	1580	29	4140	1890	51	4143	1890	61	4109	1980	72
40	3831	4340	1720	29	4388	1930	51	4330	2150	61	4285	2100	71
45	3831	4180	1620	30	4151	1800	51	4142	2070	60	4119	2050	71
50	3831	4090	1610	31	4045	1880	51	4041	2000	61	4009	2040	71
55	3831	4374	1660	33	4287	1870	52	4248	2110	61	4157	2120	71
60	3831	4054	1500	33	4157	1930	51	4144	2090	61	4086	2130	71
15	1532	1816	830	33	1869	1080	50	1878	1130	60	1893	1170	71
15	2300	2727	1160	33	2769	1410	49	2734	1510	59	2730	1560	71
15	3065	3566	1440	33	3576	1700	49	3526	1890	59	3601	1890	71
15	3831	4484	1810	33	4463	2050	50	4445	2190	59	4357	2240	71
15	4598	5334	3500	33	5328	2350	50	5249	2310	59	5282	2370	71
15	5364	6303	3450	33	6252	2430	50	6076	2490	60	6148	2460	72
15	6130	7228	3860	33	7033	2560	51	6963	2480	60	7050	2630	72
15	7050	8104	2620	34	7916	2910	51	7815	2490	62	7935	2660	72

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	89,980	44,600	598,070
49	90,756	38,580	566,270
60	90,124	40,030	599,340
71	89,878	40,980	622,080
TOTAL	360,738	164,190	2,385,760

TABLE 6: JDQ-96 REFERENCE DATA COMPARED TO CANDIDATE DATA

EOT Date: August 2, 2010

Oil Code : LO253071

Reference Oil Coded : 69X31111k	Cycles	Relative Capacity	Torque Variation	SwRI Variation	Average Facing Thickness (millimeters)
First Reference Run					
	1,000	339,375	100,390	1,204,240	7.56
	10,000	335,754	106,780	1,079,450	7.52
	20,000	334,120	84,770	1,030,270	7.49
	30,000	335,614	79,620	1,021,190	7.47
	Total	1,344,863	371,560	4,335,150	
Second Reference Run					
Run on new backing pla	1,000	343,906	79,990	1,020,120	7.48
and piston	10,000	343,056	72,520	893,570	7.30
	20,000	342,668	69,920	885,870	7.07
	30,000	345,315	70,360	833,920	6.90
	Total	1,374,945	292,790	3,633,480	
Third Reference Run					
Run on new backing pla	1,000	345,296	91,610	1,125,260	7.50
and piston	10,000	343,999	84,920	1,019,400	7.33
	20,000	342,864	94,560	1,264,070	7.22
	30,000	343,201	84,070	1,052,400	7.11
	Total	1,375,360	355,160	4,461,130	
Fourth Reference Run					
Run on new backing pla	1,000	343,305	83,380	1,067,970	7.35
and piston	10,000	341,871	76,450	1,015,030	7.10
	20,000	348,968	74,630	990,890	6.81
	30,000	341,486	102,160	1,409,300	6.48
	Total	1,375,630	336,620	4,483,190	
Fifth Reference Run					
most recent run	**1,000**	**339,979**	**113,360**	**1,597,370**	**7.34**
Run on new backing	**10,000**	**346,558**	**88,740**	**1,158,820**	**7.11**
plate and piston	**20,000**	**343,274**	**104,780**	**1,426,100**	**6.89**
	30,000	**342,255**	**113,750**	**1,642,930**	**6.69**
	Total	**1,372,066**	**420,630**	**5,825,220**	
LO253071		Candidate Oil Test Results			
run on new piston and	1,000	360,738	164,190	2,385,760	
backing plate	10,000				
	20,000				
	30,000				
	Total	360,738	164,190	2,385,760	

July 26, 2010

TABLE 7 : JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES
This was a reference test conducted before the candidate run, new piston and backing plate

SwRI Oil Code LO-238649 Sponsor Oil Code 69X31111m

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	4070	1690	29	4324	1360	48	4283	1240	59	4308	1370	70
10	3831	4292	1750	29	4289	1500	48	4259	1520	59	4232	1510	69
15	3831	4255	1760	29	4282	1630	48	4255	1700	59	4232	1760	69
20	3831	4232	1740	29	4217	1660	48	4177	1700	59	4175	1730	69
25	3831	4230	1680	29	4167	1540	49	4124	1630	60	4113	1660	70
30	3831	4227	1710	30	4098	1580	50	4107	1620	60	4073	1710	70
35	3831	4195	1690	31	4066	1630	49	4064	1470	60	4027	1510	70
40	3831	4291	1780	32	4145	1700	50	4110	1550	61	4091	1640	71
45	3831	4184	1640	33	4073	1690	50	4052	1550	61	4027	1510	71
50	3831	4134	1530	34	4034	1540	50	3990	1550	61	3996	1500	72
55	3831	4249	1660	35	4165	1600	50	4111	1610	61	4022	1470	72
60	3831	4156	1550	36	4056	1570	50	4034	1580	60	3999	1420	73
15	1532	1584	420	33	1648	650	49	1658	680	58	1651	690	71
15	2300	2543	930	33	2501	980	47	2515	990	56	2504	1030	68
15	3065	3422	1360	33	3357	1370	46	3338	1410	56	3306	1420	67
15	3831	4273	1710	33	4205	1820	47	4214	1810	57	4203	1770	67
15	4598	5143	2130	33	5048	2160	47	5002	2040	57	5024	2100	67
15	5364	5987	2280	33	5861	2260	47	5839	2210	58	5821	2180	68
15	6130	6830	2250	33	6678	2250	48	6724	2250	58	6591	2140	68
15	7050	7737	2250	33	7613	2280	49	7628	2230	59	7566	2270	68

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	88,033	33,510	456,010
49	86,824	32,770	473,890
60	86,481	32,340	486,170
71	85,958	32,390	491,430
TOTAL	347,296	131,010	1,907,500

Figure 1

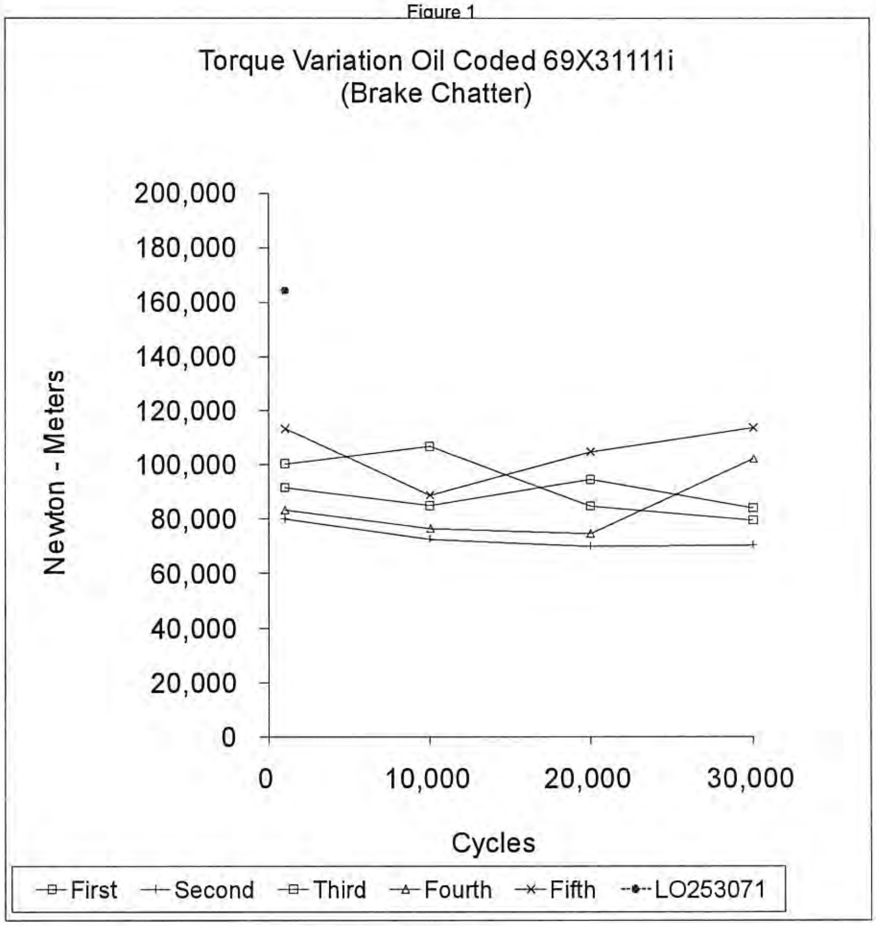


Figure 2

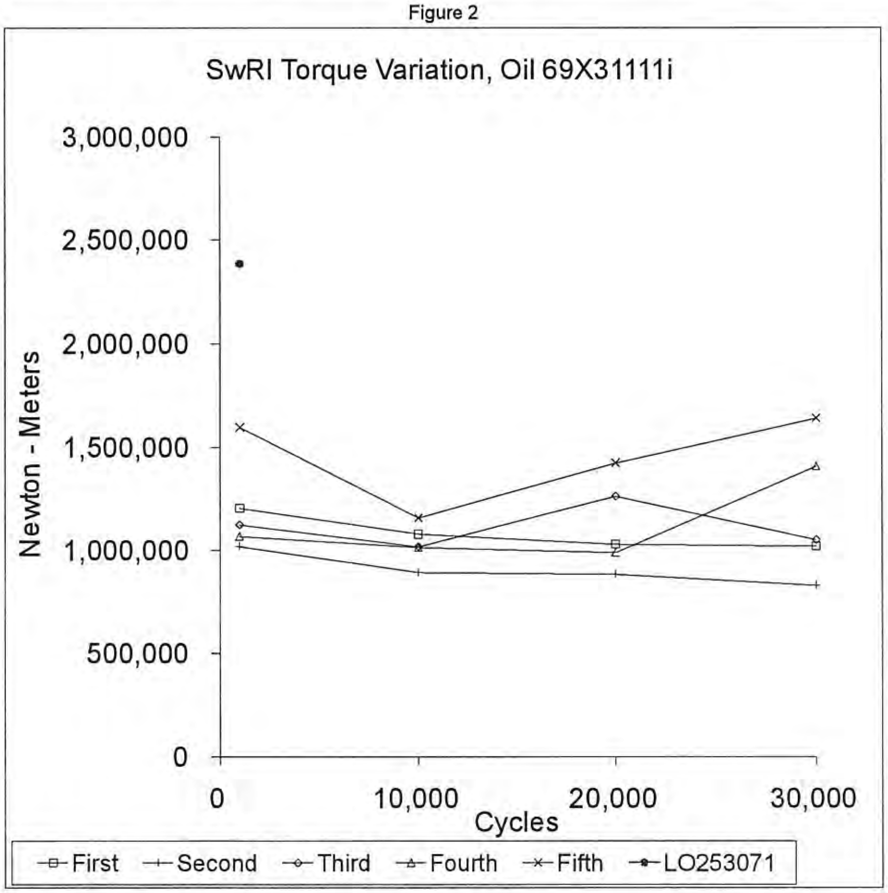


Figure 3

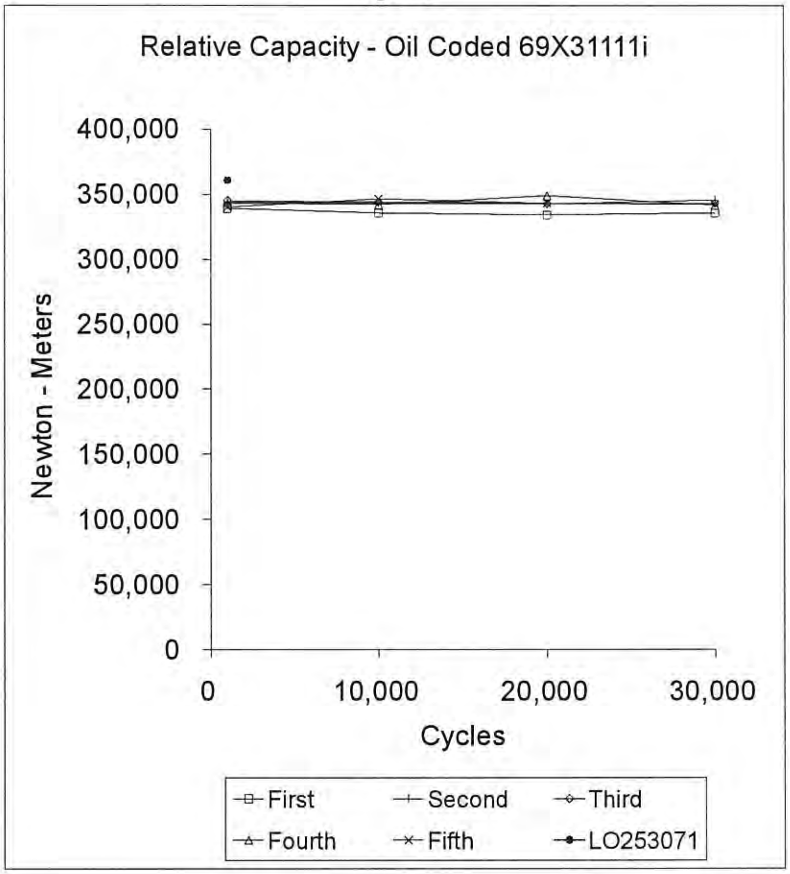
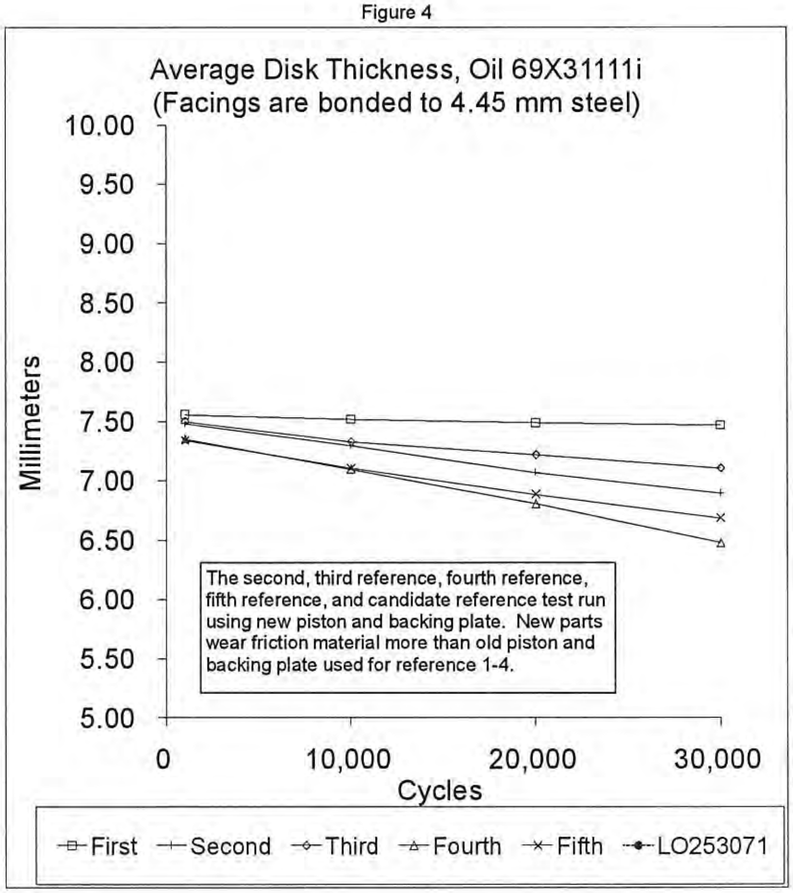
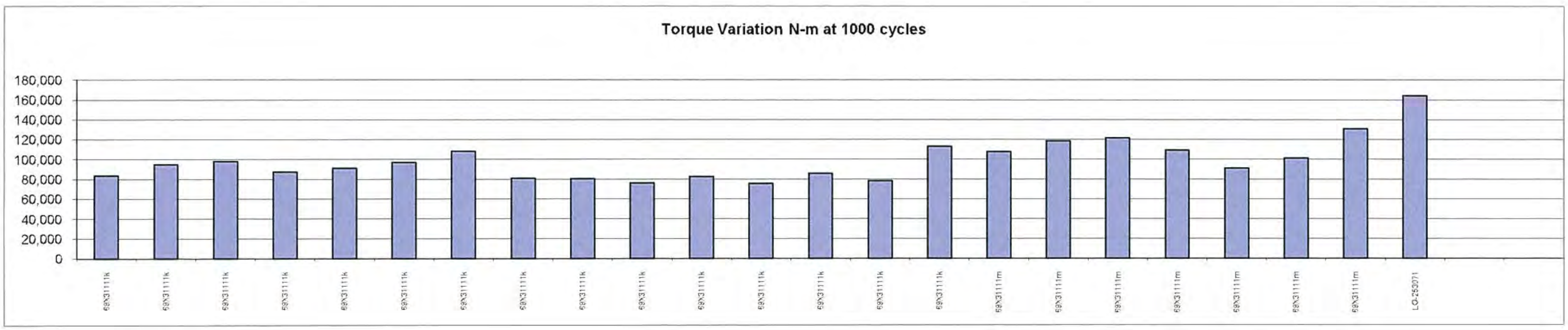


Figure 4





LO253071

August 2, 2010

Figure 5

Table 8

LO253071 August 2, 2010

History of 1000 cycle reference tests.

		Torque variation at 1000 cycles
69X31111k	new piston and backing plate	83,380
69X31111k	new piston and backing plate	94,700
69X31111k	new piston and backing plate	98,100
69X31111k	new piston and backing plate	87,510
69X31111k	new piston and backing plate	90,960
69X31111k	new piston and backing plate	96,820
69X31111k	new piston and backing plate	108,370
69X31111k	new piston and backing plate	80,950
69X31111k	new piston and backing plate	80,370
69X31111k	new piston and backing plate	76,000
69X31111k	new piston and backing plate	82,700
69X31111k	new piston and backing plate	75,670
69X31111k	new piston and backing plate	85,580
69X31111k	new piston and backing plate	78,350
69X31111k	new piston and backing plate	113,360
69X31111m	new piston and backing plate	107,620
69X31111m	new piston and backing plate	118,390
69X31111m	new piston and backing plate	121,850
69X31111m	new piston and backing plate	109,300
69X31111m	new piston and backing plate	90,980
69X31111m	new piston and backing plate	101,320
69X31111m	new piston and backing plate	131,010
LO-253071	run using piston and plate listed	164,190

APPENDIX F2. – EVALUATION OF CANDIDATE LO25054 IN JOHN DEERE JDQ-96 WET BRAKE TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

John Deere JDQ-96
Performed using 1400 Series Axle

Conducted for

U.S. ARMY TARDEC

LO254054

Test Number
10547

August 3, 2010

Submitted by:

Michael D. Lochte
Director
Specialty & Driveline Fluids
Evaluations

John Deere JDQ-96 Performed using 1400 Series Axle

General Information

Oil Code: LO253071	E.O.T. Date: August 2, 2010

Purpose

The purpose of this test was to evaluate the anti-chatter properties of this oil on the brakes of a 1400 series John Deere Inboard Planetary Axle.

Test Procedure

The test was performed as specified by John Deere Product Engineering. The only changes made to the Deere procedure were those necessary to compensate for a different spiral bevel gear ratio. This procedure is proprietary to Deere and Company.

Data Interpretation

The capacity for each engagement is the average torque during the middle of the engagement. The torque variation is the greatest difference between the maximum and minimum torque recorded during any 0.2-second portion of the engagement. The SwRI variation is the sum of all differences between the maximum torque and minimum torque for each engagement. It is obtained by summing all torque variations of each 0.2-second time block of all engagements.

Test Number

The run number listed on this report is a random number and is not sequential. Only SwRI® can link this run number to JDQ-96, LO254054, August 3, 2010.

John Deere JDQ-96 Performed using 1400 Series Axle

Results

Oil Code: LO254054	**E.O.T. Date:** August 3, 2010

The candidate results can be compared to the baseline reference average. Pass or fail decisions are only made by John Deere Product Engineering. The current reference baseline average is the average of the five most recent tests.

Current Reference Baseline Average (N · m)					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	342,372	342,248	342,379	341,574	1,368,573
Torque Variation	93,746	85,882	85,732	89,992	355,352

Results From Test Candidate LO254054					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	386,450	---	---	---	386,450
Torque Variation	192,440**	---	---	---	192,440

* This test was run for 1,000 cycles per customer's request.
** This oil created high levels of brake noise.

Table 1 of the Appendix contains chatter test results from 1,000 cycles. Table 6 contains results of the five current baseline reference tests. Figures 1 through 4 are graphic presentations of candidate oil performance compared to baseline reference data.

Table 7 contains the results of the 1000-cycle reference test that was conducted before the test on LO254054. Figure 5 is a graphic presentation of 1000-cycle reference results on LO254054. Table 8 contains the history of tests conducted on reference oil.

John Deere JDQ-96 Performed using 1400 Series Axle

Oil Code: LO254054	E.O.T. Date: August 3, 2010

Appendix

Tables

August 3, 2010

TABLE 1: JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES

SwRI Oil Code LO254054 Sponsor Oil Code LO-254054

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	4445	4170	27	4865	1660	49	4826	1670	60	4766	1710	72
10	3831	4381	3780	27	4870	1910	50	4797	2000	61	4792	2000	71
15	3831	4522	2960	27	4824	2060	49	4766	2210	60	4719	2390	71
20	3831	4584	1970	27	4691	2070	50	4687	2160	61	4671	2380	71
25	3831	4548	1920	27	4629	2020	50	4626	2150	62	4621	2380	72
30	3831	4532	1920	28	4549	2160	49	4606	2330	62	4639	2390	72
35	3831	4503	1910	29	4476	2120	49	4490	2210	59	4549	2280	71
40	3831	4738	2140	29	4720	2270	49	4657	2350	59	4718	2330	71
45	3831	4592	1860	30	4537	2140	48	4628	2360	59	4600	2370	70
50	3831	4505	1880	31	4469	2020	49	4533	2210	61	4551	2310	71
55	3831	4164	5220	33	3655	5510	50	2699	5650	60	4650	2230	71
60	3831	4634	1770	33	4638	2060	50	4606	2320	59	4672	2210	71
15	1532	1939	930	34	1998	1160	50	2042	1150	59	2030	1240	71
15	2300	2839	1280	33	2933	1550	50	2959	1680	59	2868	1700	72
15	3065	3824	1530	32	3844	1920	50	3852	2080	59	3815	2180	72
15	3831	4804	2090	32	4724	2280	51	4800	2320	60	4714	2470	72
15	4598	5653	4020	32	5711	2550	51	5704	2650	60	5690	2640	72
15	5364	6719	4270	32	6512	2650	51	6543	2690	60	6560	2760	72
15	6130	7747	4290	32	7598	2680	52	7391	2810	60	7458	2700	72
15	7050	8761	3450	32	8515	2850	52	8453	2950	61	8511	2820	71

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	96,435	53,360	651,490
49	96,757	45,640	627,670
60	95,666	47,950	671,070
71	97,593	45,490	682,300
TOTAL	386,450	192,440	2,632,530

TABLE 6: JDQ-96 REFERENCE DATA COMPARED TO CANDIDATE DATA

EOT Date: August 3, 2010

Oil Code : LO254054

Reference Oil Coded : 69X31111k	Cycles	Relative Capacity	Torque Variation	SwRI Variation	Average Facing Thickness (millimeters)
First Reference Run					
	1,000	339,375	100,390	1,204,240	7.56
	10,000	335,754	106,780	1,079,450	7.52
	20,000	334,120	84,770	1,030,270	7.49
	30,000	335,614	79,620	1,021,190	7.47
	Total	1,344,863	371,560	4,335,150	
Second Reference Run					
Run on new backing pla	1,000	343,906	79,990	1,020,120	7.48
and piston	10,000	343,056	72,520	893,570	7.30
	20,000	342,668	69,920	885,870	7.07
	30,000	345,315	70,360	833,920	6.90
	Total	1,374,945	292,790	3,633,480	
Third Reference Run					
Run on new backing pla	1,000	345,296	91,610	1,125,260	7.50
and piston	10,000	343,999	84,920	1,019,400	7.33
	20,000	342,864	94,560	1,264,070	7.22
	30,000	343,201	84,070	1,052,400	7.11
	Total	1,375,360	355,160	4,461,130	
Fourth Reference Run					
Run on new backing pla	1,000	343,305	83,380	1,067,970	7.35
and piston	10,000	341,871	76,450	1,015,030	7.10
	20,000	348,968	74,630	990,890	6.81
	30,000	341,486	102,160	1,409,300	6.48
	Total	1,375,630	336,620	4,483,190	
Fifth Reference Run					
most recent run	**1,000**	**339,979**	**113,360**	**1,597,370**	**7.34**
Run on new backing	**10,000**	**346,558**	**88,740**	**1,158,820**	**7.11**
plate and piston	**20,000**	**343,274**	**104,780**	**1,426,100**	**6.89**
	30,000	**342,255**	**113,750**	**1,642,930**	**6.69**
	Total	**1,372,066**	**420,630**	**5,825,220**	
LO254054		Candidate Oil Test Results			
run on new piston and	1,000	386,450	192,440	2,632,530	
backing plate	10,000				
	20,000				
	30,000				
	Total	386,450	192,440	2,632,530	

July 26, 2010

TABLE 7 : JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES
This was a reference test conducted before the candidate run, new piston and backing plate

SwRI Oil Code LO-238649 Sponsor Oil Code 69X31111m

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	4070	1690	29	4324	1360	48	4283	1240	59	4308	1370	70
10	3831	4292	1750	29	4289	1500	48	4259	1520	59	4232	1510	69
15	3831	4255	1760	29	4282	1630	48	4255	1700	59	4232	1760	69
20	3831	4232	1740	29	4217	1660	48	4177	1700	59	4175	1730	69
25	3831	4230	1680	29	4167	1540	49	4124	1630	60	4113	1660	70
30	3831	4227	1710	30	4098	1580	50	4107	1620	60	4073	1710	70
35	3831	4195	1690	31	4066	1630	49	4064	1470	60	4027	1510	70
40	3831	4291	1780	32	4145	1700	50	4110	1550	61	4091	1640	71
45	3831	4184	1640	33	4073	1690	50	4052	1550	61	4027	1510	71
50	3831	4134	1530	34	4034	1540	50	3990	1550	61	3996	1500	72
55	3831	4249	1660	35	4165	1600	50	4111	1610	61	4022	1470	72
60	3831	4156	1550	36	4056	1570	50	4034	1580	60	3999	1420	73
15	1532	1584	420	33	1648	650	49	1658	680	58	1651	690	71
15	2300	2543	930	33	2501	980	47	2515	990	56	2504	1030	68
15	3065	3422	1360	33	3357	1370	46	3338	1410	56	3306	1420	67
15	3831	4273	1710	33	4205	1820	47	4214	1810	57	4203	1770	67
15	4598	5143	2130	33	5048	2160	47	5002	2040	57	5024	2100	67
15	5364	5987	2280	33	5861	2260	47	5839	2210	58	5821	2180	68
15	6130	6830	2250	33	6678	2250	48	6724	2250	58	6591	2140	68
15	7050	7737	2250	33	7613	2280	49	7628	2230	59	7566	2270	68

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	88,033	33,510	456,010
49	86,824	32,770	473,890
60	86,481	32,340	486,170
71	85,958	32,390	491,430
TOTAL	347,296	131,010	1,907,500

Figure 1

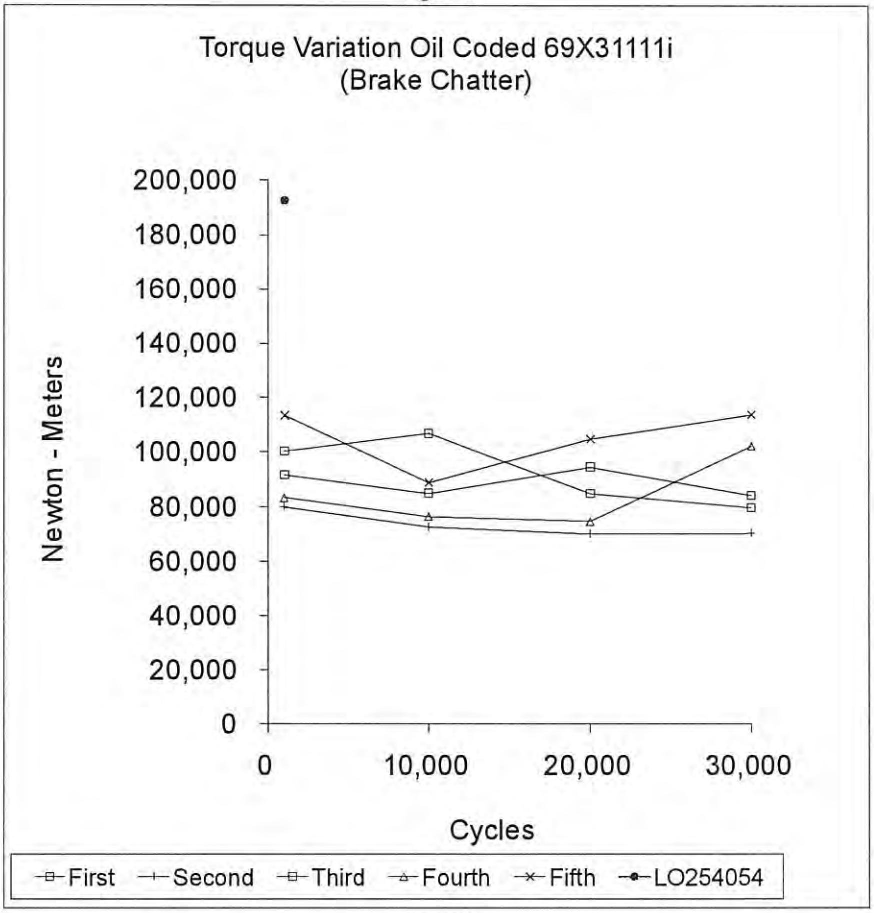


Figure 2

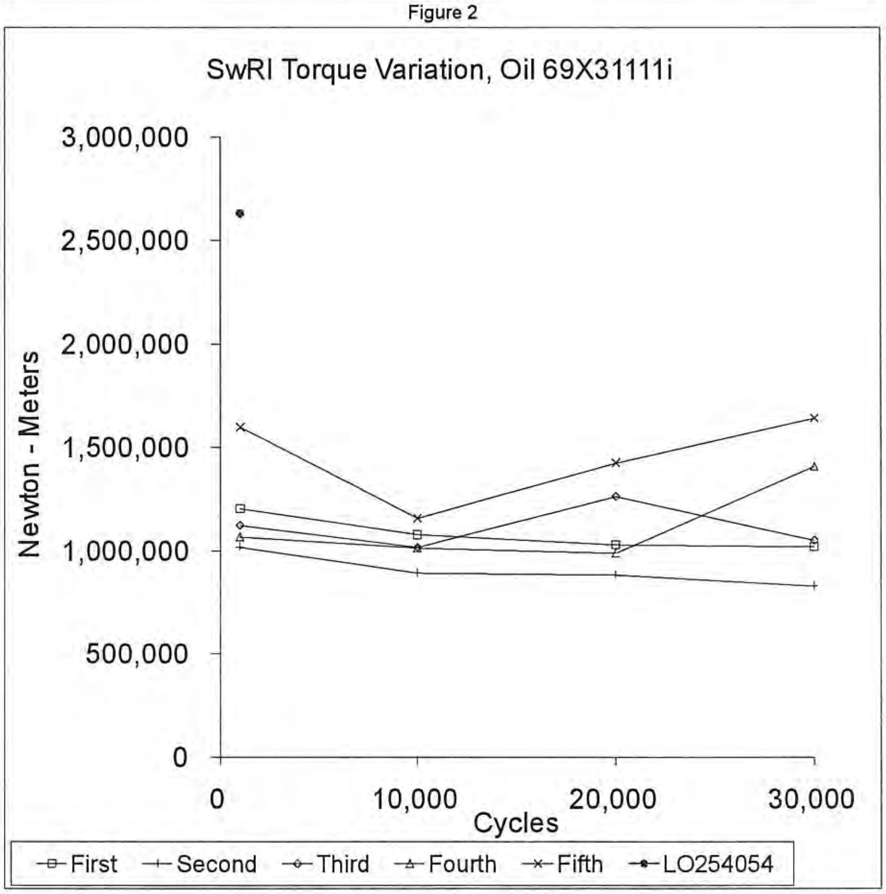


Figure 3

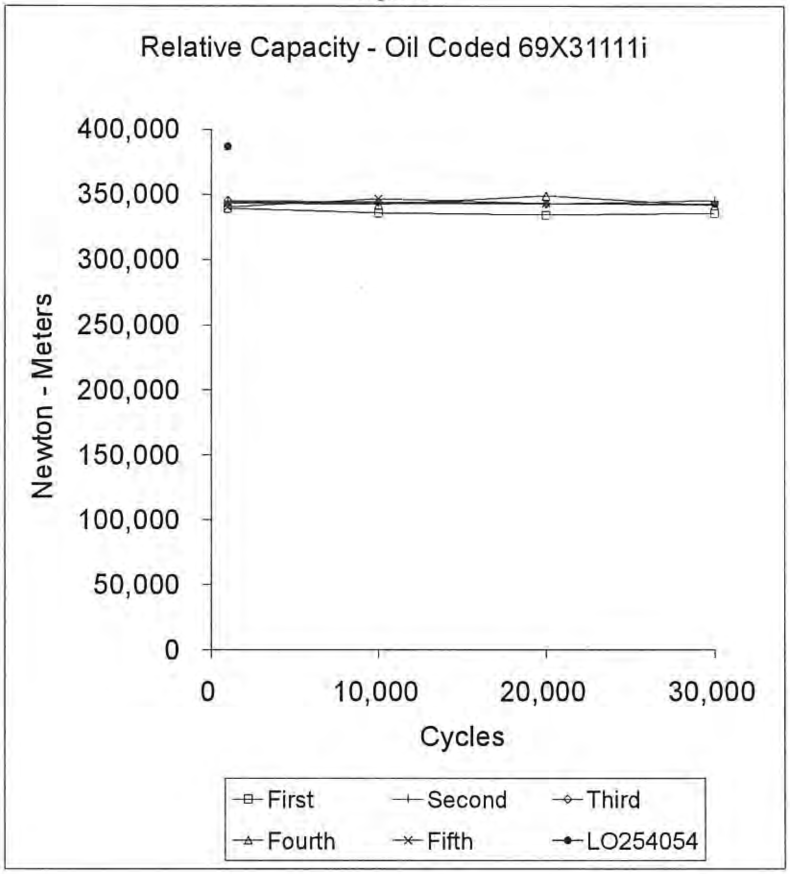
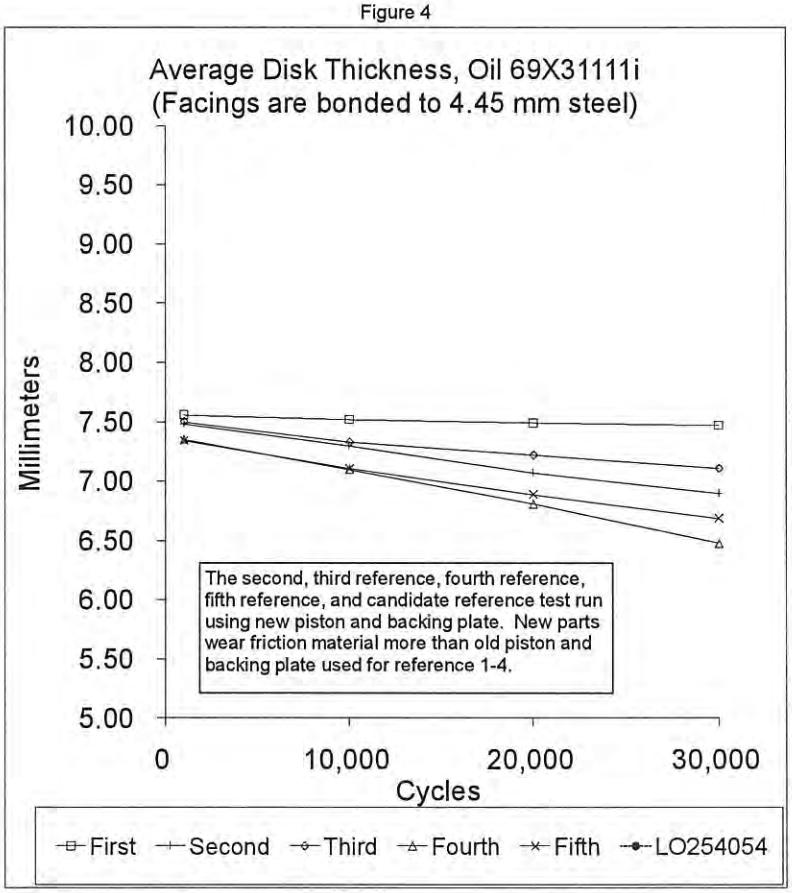
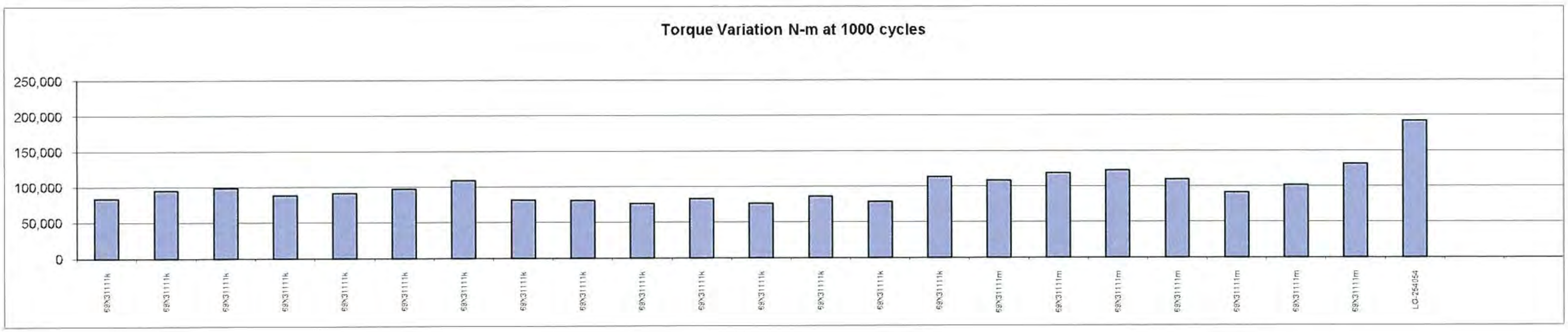


Figure 4





LO254054

August 3, 2010

Figure 5

LO254054 | Table 8 | August 3, 2010

History of 1000 cycle reference tests.

		Torque variation at 1000 cycles
69X31111k	new piston and backing plate	83,380
69X31111k	new piston and backing plate	94,700
69X31111k	new piston and backing plate	98,100
69X31111k	new piston and backing plate	87,510
69X31111k	new piston and backing plate	90,960
69X31111k	new piston and backing plate	96,820
69X31111k	new piston and backing plate	108,370
69X31111k	new piston and backing plate	80,950
69X31111k	new piston and backing plate	80,370
69X31111k	new piston and backing plate	76,000
69X31111k	new piston and backing plate	82,700
69X31111k	new piston and backing plate	75,670
69X31111k	new piston and backing plate	85,580
69X31111k	new piston and backing plate	78,350
69X31111k	new piston and backing plate	113,360
69X31111m	new piston and backing plate	107,620
69X31111m	new piston and backing plate	118,390
69X31111m	new piston and backing plate	121,850
69X31111m	new piston and backing plate	109,300
69X31111m	new piston and backing plate	90,980
69X31111m	new piston and backing plate	101,320
69X31111m	new piston and backing plate	131,010
LO-254054	run using piston and plate listed	192,440

APPENDIX F3. – EVALUATION OF CANDIDATE LO25033 IN JOHN DEERE JDQ-96 WET BRAKE TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

John Deere JDQ-96
Performed using 1400 Series Axle

Conducted for

U.S. ARMY TARDEC

LO250033

Test Number
10827

July 30, 2010

Submitted by:

Michael D. Lochte
Director
Specialty & Driveline Fluids
Evaluations

John Deere JDQ-96 Performed using 1400 Series Axle

General Information

Oil Code: LO250033	E.O.T. Date: July 30, 2010

Purpose

The purpose of this test was to evaluate the anti-chatter properties of this oil on the brakes of a 1400 series John Deere Inboard Planetary Axle.

Test Procedure

The test was performed as specified by John Deere Product Engineering. The only changes made to the Deere procedure were those necessary to compensate for a different spiral bevel gear ratio. This procedure is proprietary to Deere and Company.

Data Interpretation

The capacity for each engagement is the average torque during the middle of the engagement. The torque variation is the greatest difference between the maximum and minimum torque recorded during any 0.2-second portion of the engagement. The SwRI variation is the sum of all differences between the maximum torque and minimum torque for each engagement. It is obtained by summing all torque variations of each 0.2-second time block of all engagements.

Test Number

The run number listed on this report is a random number and is not sequential. Only SwRI® can link this run number to JDQ-96, LO250033, July 30, 2010.

John Deere JDQ-96 Performed using 1400 Series Axle

Results

Oil Code: LO250033	**E.O.T. Date:** July 30, 2010

The candidate results can be compared to the baseline reference average. Pass or fail decisions are only made by John Deere Product Engineering. The current reference baseline average is the average of the five most recent tests.

Current Reference Baseline Average (N · m)					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	342,372	342,248	342,379	341,574	1,368,573
Torque Variation	93,746	85,882	85,732	89,992	355,352

Results From Test Candidate LO250033					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	403,778*	---	---	---	403,778
Torque Variation	255,990**	---	---	---	255,990

* This test was run for 1,000 cycles per customer's request.
** This oil created high levels of brake noise.

Table 1 of the Appendix contains chatter test results from 1,000 cycles. Table 6 contains results of the five current baseline reference tests. Figures 1 through 4 are graphic presentations of candidate oil performance compared to baseline reference data.

Table 7 contains the results of the 1000-cycle reference test that was conducted before the test on LO250033. Figure 5 is a graphic presentation of 1000-cycle reference results on LO250033. Table 8 contains the history of tests conducted on reference oil.

John Deere JDQ-96 Performed using 1400 Series Axle

Oil Code: LO250033	E.O.T. Date: July 30, 2010

Appendix

Tables

July 30, 2010

TABLE 1: JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES

SwRI Oil Code LO-250033

Sponsor Oil Code LO250033

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	4399	3640	29	5014	2810	48	5180	2190	59	5255	2280	69
10	3831	4670	3910	29	5164	2110	48	5119	2310	59	5154	2350	69
15	3831	4594	3020	29	4792	3390	48	5130	2530	59	5127	2720	69
20	3831	4831	2130	29	5019	2200	48	5073	2570	60	5153	2890	69
25	3831	4831	2150	30	4959	2120	49	5026	2420	60	5092	2710	70
30	3831	4863	2140	30	5031	2360	49	5078	2640	60	5170	2970	70
35	3831	4810	2050	31	4961	2220	49	5028	2580	61	5117	2620	70
40	3831	5075	2210	32	4303	6140	50	3159	6090	61	3841	6190	70
45	3831	4848	2130	33	5157	2450	50	4914	2790	57	5175	2880	70
50	3831	4774	2120	33	5101	2560	49	4970	2840	58	5064	2860	70
55	3831	2104	6150	34	2597	6190	50	4628	6320	59	4506	6110	70
60	3831	4984	2140	35	3356	6430	49	4511	6070	59	4627	6080	71
15	1532	1812	870	34	1870	1020	47	1862	1170	59	1945	1250	71
15	2300	2824	1310	34	2931	1500	47	2904	1680	59	3020	1710	71
15	3065	3872	1860	34	3955	2030	48	4020	2240	59	4064	2320	70
15	3831	4969	2300	34	4836	3900	48	5076	2630	59	5047	2890	71
15	4598	5835	4650	33	5793	4290	48	5966	3010	59	6071	3100	71
15	5364	6882	4930	34	7003	4650	49	7082	3310	60	7216	3410	71
15	6130	7975	5090	34	8160	3780	49	7990	3840	60	8279	4100	71
15	7050	9228	5260	35	9119	4160	49	9214	3860	60	9627	5090	72

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	98,179	60,060	705,060
49	99,121	66,310	735,130
60	101,930	63,090	789,690
71	104,548	66,530	848,170
TOTAL	403,778	255,990	3,078,050

TABLE 6: JDQ-96 REFERENCE DATA COMPARED TO CANDIDATE DATA

EOT Date: July 30, 2010

Oil Code : LO250033

Reference Oil Coded : 69X31111k	Cycles	Relative Capacity	Torque Variation	SwRI Variation	Average Facing Thickness (millimeters)
First Reference Run					
	1,000	339,375	100,390	1,204,240	7.56
	10,000	335,754	106,780	1,079,450	7.52
	20,000	334,120	84,770	1,030,270	7.49
	30,000	335,614	79,620	1,021,190	7.47
	Total	1,344,863	371,560	4,335,150	
Second Reference Run					
Run on new backing pla	1,000	343,906	79,990	1,020,120	7.48
and piston	10,000	343,056	72,520	893,570	7.30
	20,000	342,668	69,920	885,870	7.07
	30,000	345,315	70,360	833,920	6.90
	Total	1,374,945	292,790	3,633,480	
Third Reference Run					
Run on new backing pla	1,000	345,296	91,610	1,125,260	7.50
and piston	10,000	343,999	84,920	1,019,400	7.33
	20,000	342,864	94,560	1,264,070	7.22
	30,000	343,201	84,070	1,052,400	7.11
	Total	1,375,360	355,160	4,461,130	
Fourth Reference Run					
Run on new backing pla	1,000	343,305	83,380	1,067,970	7.35
and piston	10,000	341,871	76,450	1,015,030	7.10
	20,000	348,968	74,630	990,890	6.81
	30,000	341,486	102,160	1,409,300	6.48
	Total	1,375,630	336,620	4,483,190	
Fifth Reference Run					
most recent run	**1,000**	**339,979**	**113,360**	**1,597,370**	**7.34**
Run on new backing	**10,000**	**346,558**	**88,740**	**1,158,820**	**7.11**
plate and piston	**20,000**	**343,274**	**104,780**	**1,426,100**	**6.89**
	30,000	**342,255**	**113,750**	**1,642,930**	**6.69**
	Total	**1,372,066**	**420,630**	**5,825,220**	
LO250033		Candidate Oil Test Results			
run on new piston and	1,000	403,778	255,990	3,078,050	
backing plate	10,000				
	20,000				
	30,000				
	Total	403,778	255,990	3,078,050	

TABLE 7 : JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES
This was a reference test conducted before the candidate run, new piston and backing plate

SwRI Oil Code LO-238649 Sponsor Oil Code 69X31111m

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	4070	1690	29	4324	1360	48	4283	1240	59	4308	1370	70
10	3831	4292	1750	29	4289	1500	48	4259	1520	59	4232	1510	69
15	3831	4255	1760	29	4282	1630	48	4255	1700	59	4232	1760	69
20	3831	4232	1740	29	4217	1660	48	4177	1700	59	4175	1730	69
25	3831	4230	1680	29	4167	1540	49	4124	1630	60	4113	1660	70
30	3831	4227	1710	30	4098	1580	50	4107	1620	60	4073	1710	70
35	3831	4195	1690	31	4066	1630	49	4064	1470	60	4027	1510	70
40	3831	4291	1780	32	4145	1700	50	4110	1550	61	4091	1640	71
45	3831	4184	1640	33	4073	1690	50	4052	1550	61	4027	1510	71
50	3831	4134	1530	34	4034	1540	50	3990	1550	61	3996	1500	72
55	3831	4249	1660	35	4165	1600	50	4111	1610	61	4022	1470	72
60	3831	4156	1550	36	4056	1570	50	4034	1580	60	3999	1420	73
15	1532	1584	420	33	1648	650	49	1658	680	58	1651	690	71
15	2300	2543	930	33	2501	980	47	2515	990	56	2504	1030	68
15	3065	3422	1360	33	3357	1370	46	3338	1410	56	3306	1420	67
15	3831	4273	1710	33	4205	1820	47	4214	1810	57	4203	1770	67
15	4598	5143	2130	33	5048	2160	47	5002	2040	57	5024	2100	67
15	5364	5987	2280	33	5861	2260	47	5839	2210	58	5821	2180	68
15	6130	6830	2250	33	6678	2250	48	6724	2250	58	6591	2140	68
15	7050	7737	2250	33	7613	2280	49	7628	2230	59	7566	2270	68

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	88,033	33,510	456,010
49	86,824	32,770	473,890
60	86,481	32,340	486,170
71	85,958	32,390	491,430
TOTAL	347,296	131,010	1,907,500

Figure 1

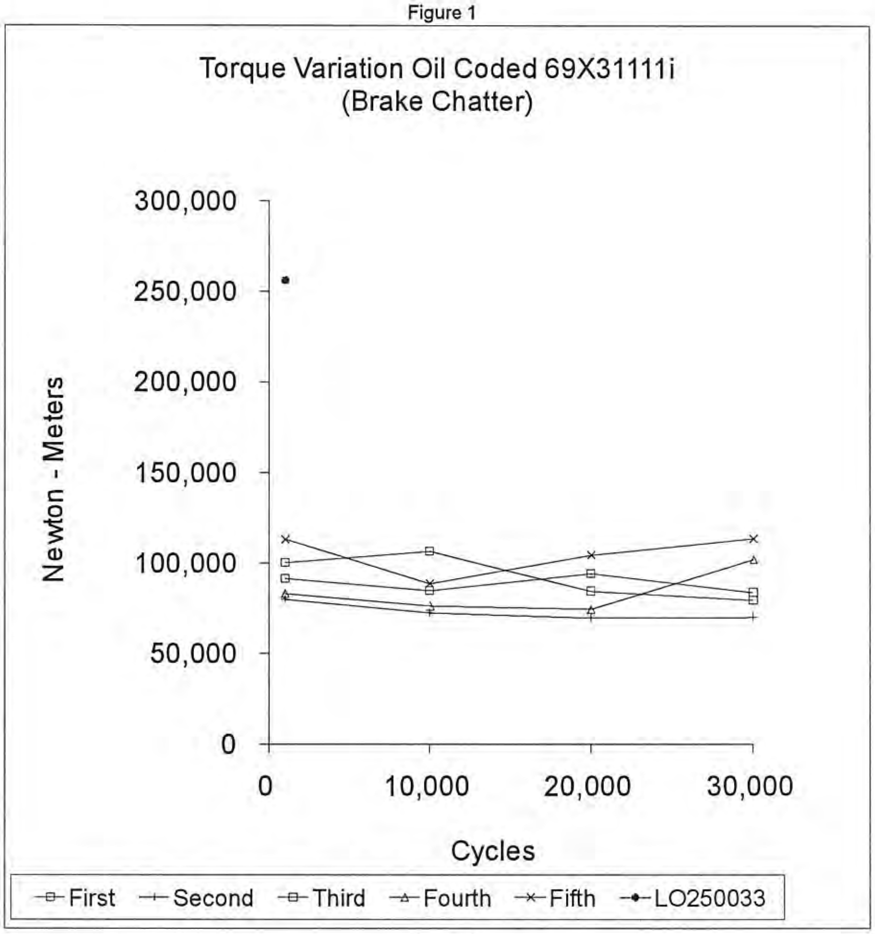


Figure 2

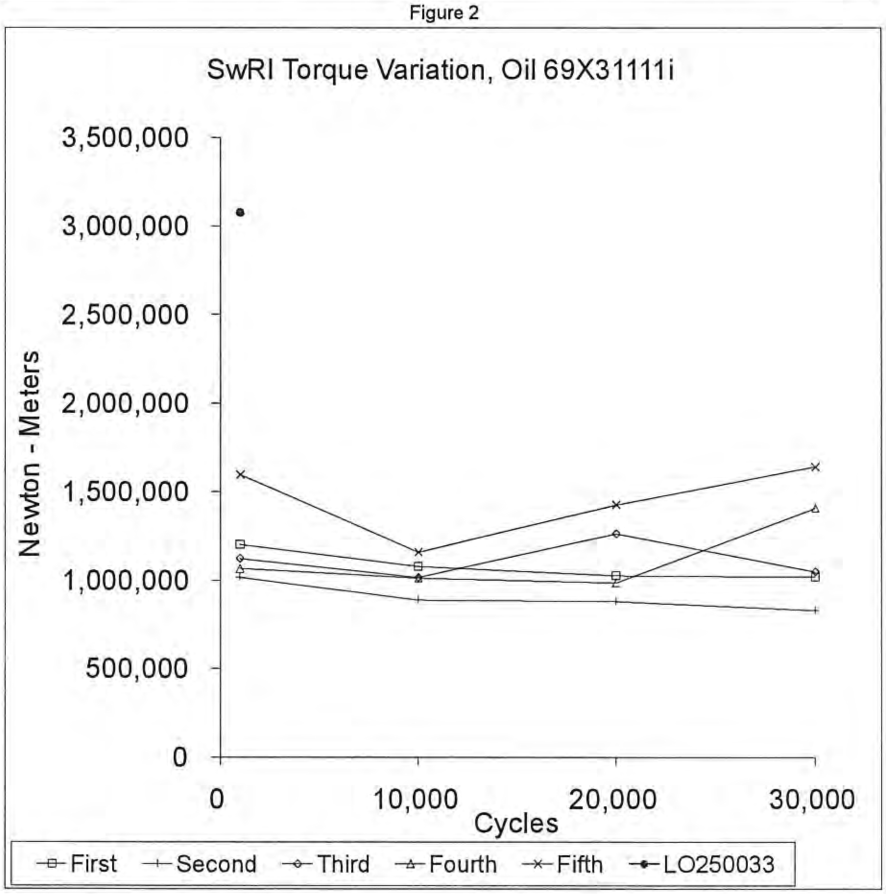


Figure 3

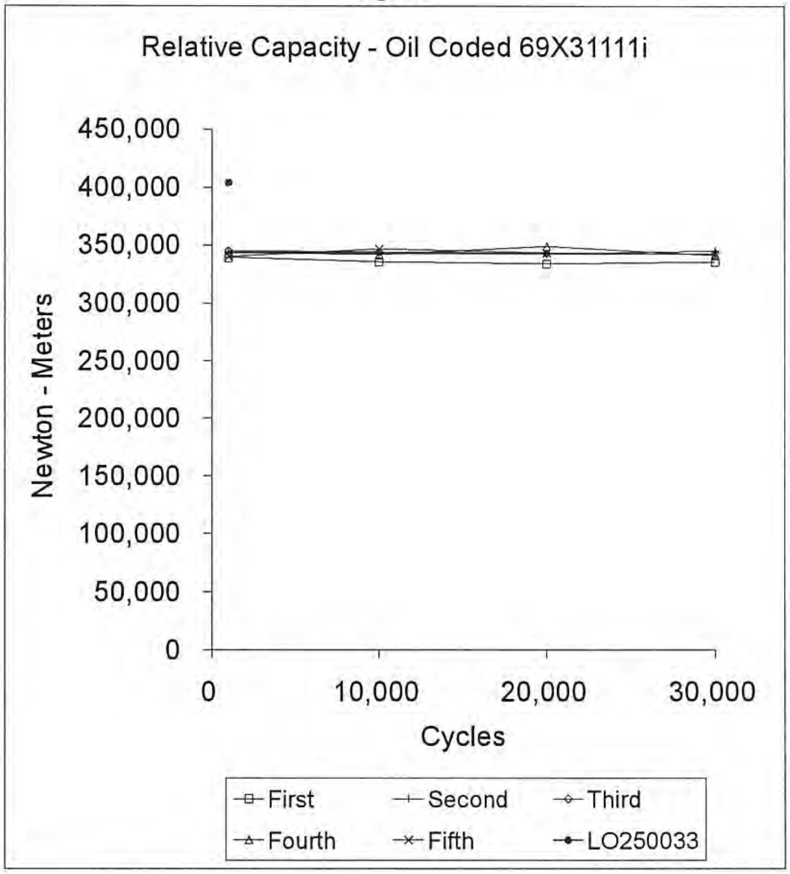
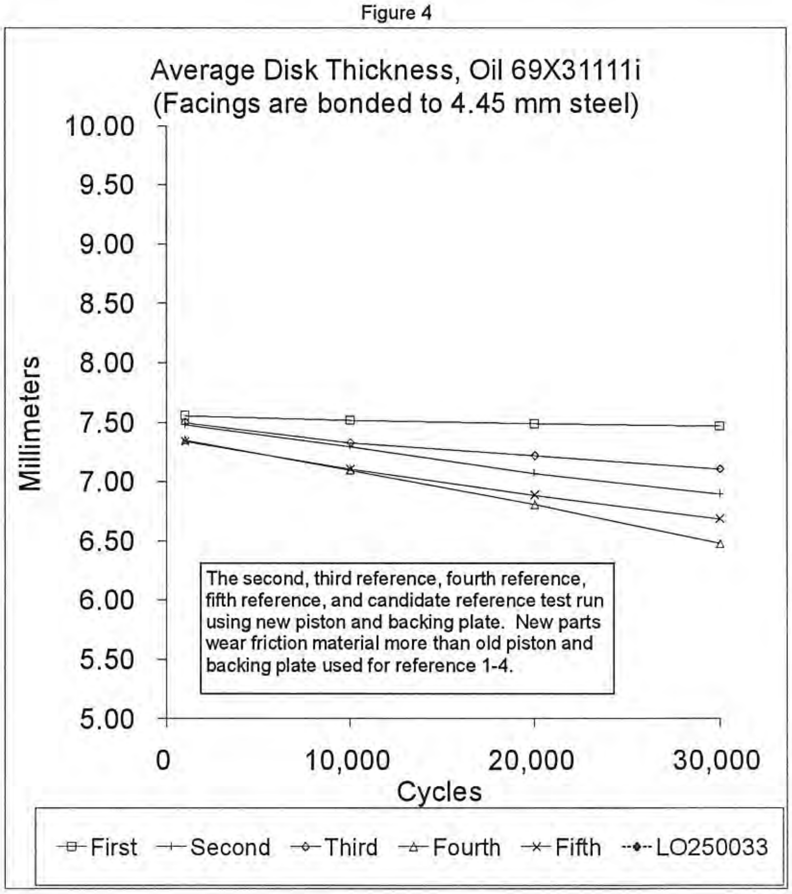
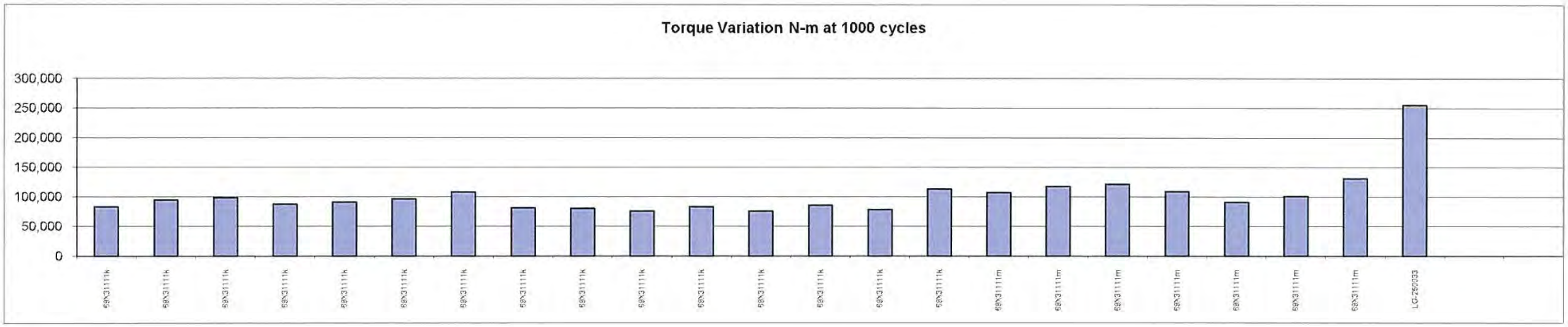


Figure 4





LO250033 July 30, 2010

Figure 5

Table 8

LO250033 July 30, 2010

History of 1000 cycle reference tests.

		Torque variation at 1000 cycles
69X31111k	new piston and backing plate	83,380
69X31111k	new piston and backing plate	94,700
69X31111k	new piston and backing plate	98,100
69X31111k	new piston and backing plate	87,510
69X31111k	new piston and backing plate	90,960
69X31111k	new piston and backing plate	96,820
69X31111k	new piston and backing plate	108,370
69X31111k	new piston and backing plate	80,950
69X31111k	new piston and backing plate	80,370
69X31111k	new piston and backing plate	76,000
69X31111k	new piston and backing plate	82,700
69X31111k	new piston and backing plate	75,670
69X31111k	new piston and backing plate	85,580
69X31111k	new piston and backing plate	78,350
69X31111k	new piston and backing plate	113,360
69X31111m	new piston and backing plate	107,620
69X31111m	new piston and backing plate	118,390
69X31111m	new piston and backing plate	121,850
69X31111m	new piston and backing plate	109,300
69X31111m	new piston and backing plate	90,980
69X31111m	new piston and backing plate	101,320
69X31111m	new piston and backing plate	131,010
LO250033	run using piston and plate listed above	255,990

APPENDIX F4. – EVALUATION OF CANDIDATE LO251746 IN JOHN DEERE JDQ-96 WET BRAKE TESTING

SOUTHWEST RESEARCH INSTITUTE®
San Antonio, Texas

Fuels and Lubricants Research Division

Report on

John Deere JDQ-96
Performed using 1400 Series Axle

Conducted for

U.S. ARMY TARDEC

LO251746

Test Number
10739

July 31, 2010

Submitted by:

Michael Lochte

Michael D. Lochte
Director
Specialty & Driveline Fluids
Evaluations

John Deere JDQ-96 Performed using 1400 Series Axle

General Information

Oil Code: LO251746	**E.O.T. Date:** July 31, 2010

Purpose

The purpose of this test was to evaluate the anti-chatter properties of this oil on the brakes of a 1400 series John Deere Inboard Planetary Axle.

Test Procedure

The test was performed as specified by John Deere Product Engineering. The only changes made to the Deere procedure were those necessary to compensate for a different spiral bevel gear ratio. This procedure is proprietary to Deere and Company.

Data Interpretation

The capacity for each engagement is the average torque during the middle of the engagement. The torque variation is the greatest difference between the maximum and minimum torque recorded during any 0.2-second portion of the engagement. The SwRI variation is the sum of all differences between the maximum torque and minimum torque for each engagement. It is obtained by summing all torque variations of each 0.2-second time block of all engagements.

Test Number

The run number listed on this report is a random number and is not sequential. Only SwRI® can link this run number to JDQ-96, LO251746, July 31, 2010.

John Deere JDQ-96 Performed using 1400 Series Axle

Results

Oil Code: LO251746	**E.O.T. Date:** July 31, 2010

The candidate results can be compared to the baseline reference average. Pass or fail decisions are only made by John Deere Product Engineering. The current reference baseline average is the average of the five most recent tests.

Current Reference Baseline Average (N · m)					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	342,372	342,248	342,379	341,574	1,368,573
Torque Variation	93,746	85,882	85,732	89,992	355,352

Results From Test Candidate LO251746					
	1,000 Cycles	**10,000 Cycles**	**20,000 Cycles**	**30,000 Cycles**	**TOTAL**
Relative Capacity	398,534	---	---	---	398,534
Torque Variation	253,990**	---	---	---	253,990

* This test was run for 1,000 cycles per customer's request.
** This oil created high levels of brake noise.

Table 1 of the Appendix contains chatter test results from 1,000 cycles. Table 6 contains results of the five current baseline reference tests. Figures 1 through 4 are graphic presentations of candidate oil performance compared to baseline reference data.

Table 7 contains the results of the 1000-cycle reference test that was conducted before the test on LO251746. Figure 5 is a graphic presentation of 1000-cycle reference results on LO251746. Table 8 contains the history of tests conducted on reference oil.

John Deere JDQ-96 Performed using 1400 Series Axle

Oil Code: LO251746	E.O.T. Date: July 31, 2010

Appendix

Tables

July 31, 2010

TABLE 1: JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES

SwRI Oil Code LO-251746 Sponsor Oil Code LO251746

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	4309	3870	29	4893	2680	49	5120	2360	60	5187	2470	71
10	3831	4338	3630	29	4929	2820	49	4892	2510	60	5119	2520	71
15	3831	4787	2650	29	5064	2420	49	5049	2600	60	5148	2840	71
20	3831	4743	1950	29	4961	2280	49	4970	2610	61	5128	3000	72
25	3831	4743	1840	29	4909	2210	50	4927	2470	61	5089	2840	72
30	3831	4722	1940	30	4923	2360	51	5044	2670	61	5098	3030	73
35	3831	4686	1930	30	4814	2310	51	4932	2510	62	5007	2760	73
40	3831	4924	2210	31	5100	2530	51	2536	5790	59	3859	6080	72
45	3831	4753	1980	32	4844	2390	50	4927	2780	58	5148	3020	70
50	3831	4647	1970	33	4863	2410	50	4897	2780	59	5079	3030	71
55	3831	2762	5810	34	3460	5740	51	3562	6190	59	4019	6330	71
60	3831	5007	2040	34	4979	2510	50	4998	2800	59	3140	6190	71
15	1532	1923	940	34	1993	1080	49	2017	1260	59	2055	1370	71
15	2300	2904	1310	34	2943	1590	49	2936	1760	59	2947	1890	71
15	3065	3770	1620	33	3888	2080	49	3947	2190	60	3996	2390	71
15	3831	4567	4440	33	4711	4070	49	5029	2670	60	4948	2880	71
15	4598	5694	4840	34	5751	4570	50	5970	3130	60	5927	3360	71
15	5364	6892	3320	34	6768	4580	50	6945	3740	60	6961	3810	72
15	6130	7677	5670	34	7876	5060	50	7947	4490	61	7836	4180	72
15	7050	8999	6260	34	9180	5530	51	9246	5150	61	9260	6100	70

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	96,847	60,220	724,820
49	100,847	61,220	771,610
60	99,891	62,460	827,770
71	100,950	70,090	905,340
TOTAL	398,534	253,990	3,229,540

TABLE 6: JDQ-96 REFERENCE DATA COMPARED TO CANDIDATE DATA

EOT Date: July 31, 2010

Oil Code : LO251746

Reference Oil Coded : 69X31111k	Cycles	Relative Capacity	Torque Variation	SwRI Variation	Average Facing Thickness (millimeters)
First Reference Run					
	1,000	339,375	100,390	1,204,240	7.56
	10,000	335,754	106,780	1,079,450	7.52
	20,000	334,120	84,770	1,030,270	7.49
	30,000	335,614	79,620	1,021,190	7.47
	Total	1,344,863	371,560	4,335,150	
Second Reference Run					
Run on new backing pla	1,000	343,906	79,990	1,020,120	7.48
and piston	10,000	343,056	72,520	893,570	7.30
	20,000	342,668	69,920	885,870	7.07
	30,000	345,315	70,360	833,920	6.90
	Total	1,374,945	292,790	3,633,480	
Third Reference Run					
Run on new backing pla	1,000	345,296	91,610	1,125,260	7.50
and piston	10,000	343,999	84,920	1,019,400	7.33
	20,000	342,864	94,560	1,264,070	7.22
	30,000	343,201	84,070	1,052,400	7.11
	Total	1,375,360	355,160	4,461,130	
Fourth Reference Run					
Run on new backing pla	1,000	343,305	83,380	1,067,970	7.35
and piston	10,000	341,871	76,450	1,015,030	7.10
	20,000	348,968	74,630	990,890	6.81
	30,000	341,486	102,160	1,409,300	6.48
	Total	1,375,630	336,620	4,483,190	
Fifth Reference Run					
most recent run	**1,000**	**339,979**	**113,360**	**1,597,370**	**7.34**
Run on new backing	**10,000**	**346,558**	**88,740**	**1,158,820**	**7.11**
plate and piston	**20,000**	**343,274**	**104,780**	**1,426,100**	**6.89**
	30,000	**342,255**	**113,750**	**1,642,930**	**6.69**
	Total	**1,372,066**	**420,630**	**5,825,220**	
LO251746		Candidate Oil Test Results			
run on new piston and	1,000	398,534	253,990	3,229,540	
backing plate	10,000				
	20,000				
	30,000				
	Total	398,534	253,990	3,229,540	

July 26, 2010

TABLE 7 : JDQ-96 DURABILITY TEST RESULTS 1,000 CYCLES
This was a reference test conducted before the candidate run, new piston and backing plate

SwRI Oil Code LO-238649 Sponsor Oil Code 69X31111m

Axle Speed (rpm)	Brake Press. (kPa)	TORQUE VARIATION TEST RESULTS (TORQUE and VARIATION in Nm)											
		Oil Temp. 32°C			Oil Temp. 49°C			Oil Temp. 60°C			Oil Temp. 71°C		
		Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.	Torque	Variation	Temp.
8	3831	4070	1690	29	4324	1360	48	4283	1240	59	4308	1370	70
10	3831	4292	1750	29	4289	1500	48	4259	1520	59	4232	1510	69
15	3831	4255	1760	29	4282	1630	48	4255	1700	59	4232	1760	69
20	3831	4232	1740	29	4217	1660	48	4177	1700	59	4175	1730	69
25	3831	4230	1680	29	4167	1540	49	4124	1630	60	4113	1660	70
30	3831	4227	1710	30	4098	1580	50	4107	1620	60	4073	1710	70
35	3831	4195	1690	31	4066	1630	49	4064	1470	60	4027	1510	70
40	3831	4291	1780	32	4145	1700	50	4110	1550	61	4091	1640	71
45	3831	4184	1640	33	4073	1690	50	4052	1550	61	4027	1510	71
50	3831	4134	1530	34	4034	1540	50	3990	1550	61	3996	1500	72
55	3831	4249	1660	35	4165	1600	50	4111	1610	61	4022	1470	72
60	3831	4156	1550	36	4056	1570	50	4034	1580	60	3999	1420	73
15	1532	1584	420	33	1648	650	49	1658	680	58	1651	690	71
15	2300	2543	930	33	2501	980	47	2515	990	56	2504	1030	68
15	3065	3422	1360	33	3357	1370	46	3338	1410	56	3306	1420	67
15	3831	4273	1710	33	4205	1820	47	4214	1810	57	4203	1770	67
15	4598	5143	2130	33	5048	2160	47	5002	2040	57	5024	2100	67
15	5364	5987	2280	33	5861	2260	47	5839	2210	58	5821	2180	68
15	6130	6830	2250	33	6678	2250	48	6724	2250	58	6591	2140	68
15	7050	7737	2250	33	7613	2280	49	7628	2230	59	7566	2270	68

Temp (°C)	Relative Capacity (Nm)	Torque Variation (Nm)	SwRI Variation (Nm)
32	88,033	33,510	456,010
49	86,824	32,770	473,890
60	86,481	32,340	486,170
71	85,958	32,390	491,430
TOTAL	347,296	131,010	1,907,500

Figure 1

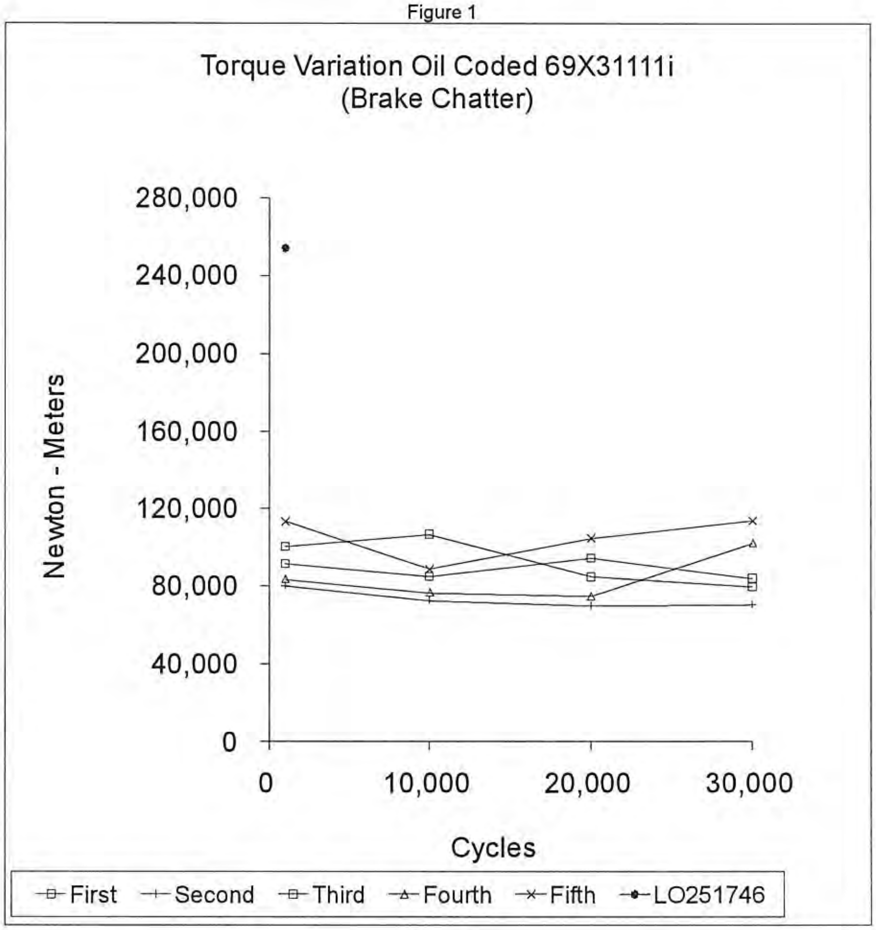


Figure 2

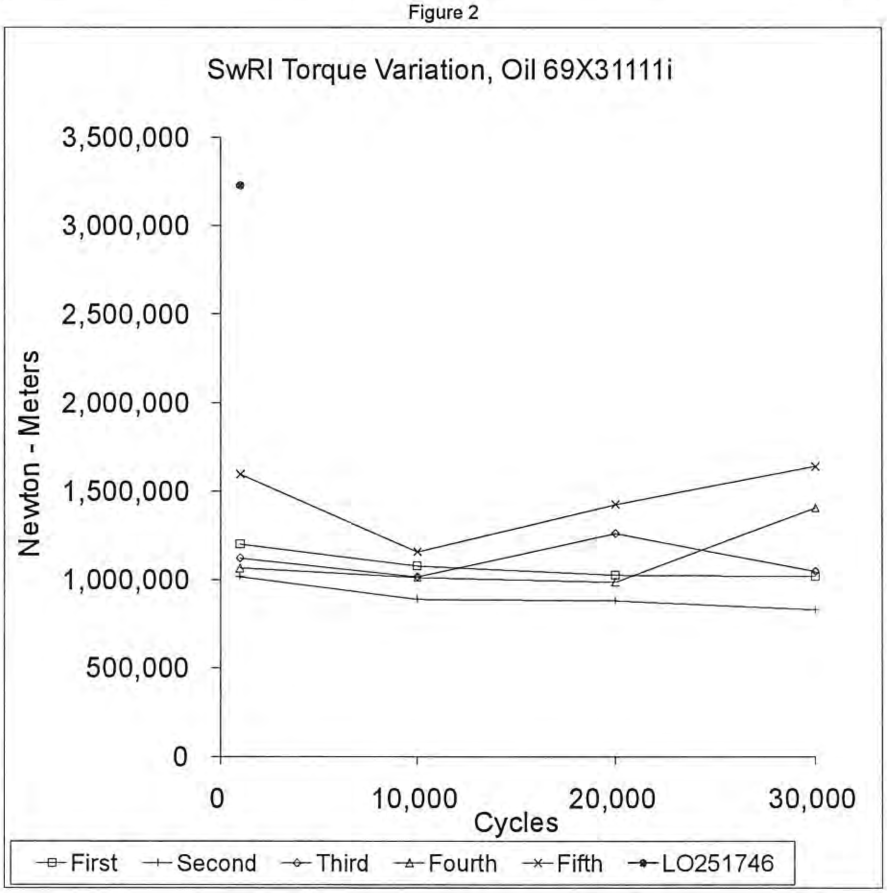


Figure 3

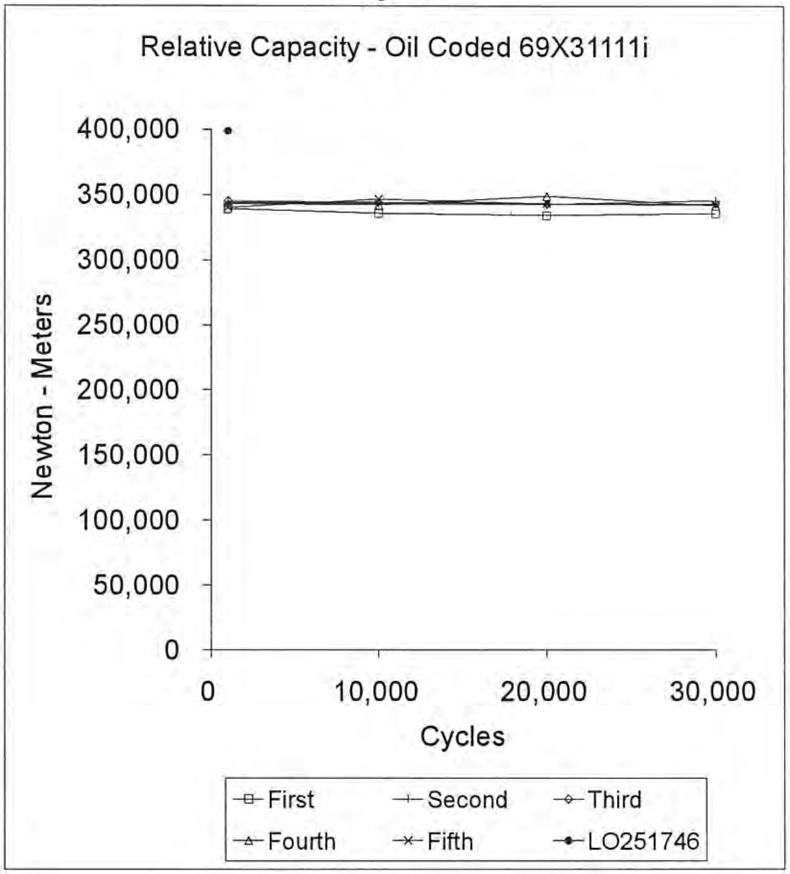
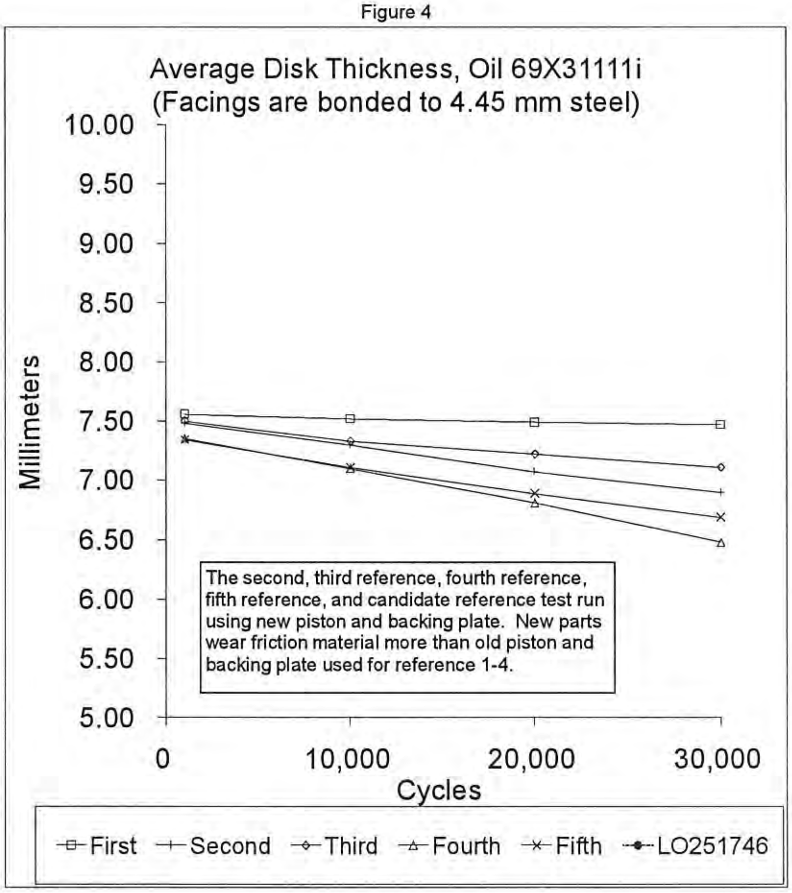
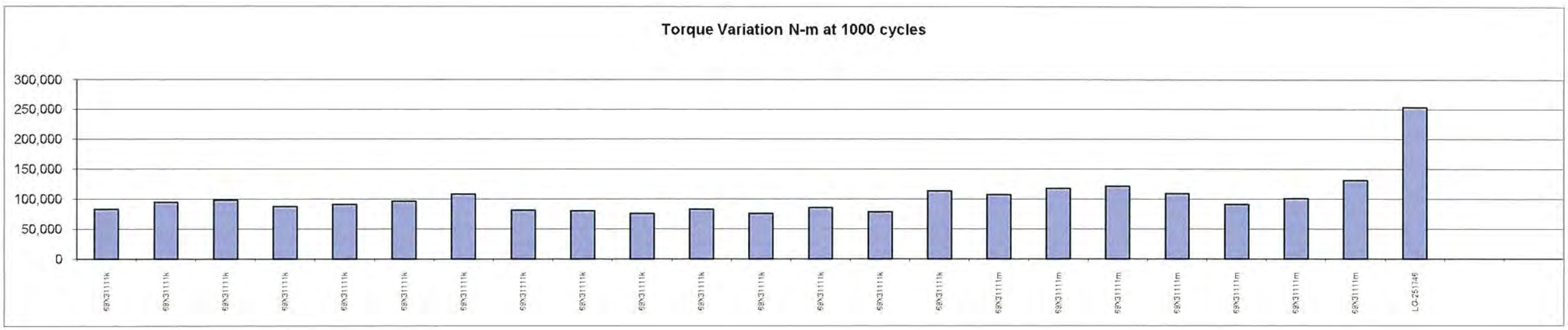


Figure 4





LO251746 July 31, 2010

Figure 5

Table 8

LO251746 July 31, 2010

History of 1000 cycle reference tests.

		Torque variation at 1000 cycles
69X31111k	new piston and backing plate	83,380
69X31111k	new piston and backing plate	94,700
69X31111k	new piston and backing plate	98,100
69X31111k	new piston and backing plate	87,510
69X31111k	new piston and backing plate	90,960
69X31111k	new piston and backing plate	96,820
69X31111k	new piston and backing plate	108,370
69X31111k	new piston and backing plate	80,950
69X31111k	new piston and backing plate	80,370
69X31111k	new piston and backing plate	76,000
69X31111k	new piston and backing plate	82,700
69X31111k	new piston and backing plate	75,670
69X31111k	new piston and backing plate	85,580
69X31111k	new piston and backing plate	78,350
69X31111k	new piston and backing plate	113,360
69X31111m	new piston and backing plate	107,620
69X31111m	new piston and backing plate	118,390
69X31111m	new piston and backing plate	121,850
69X31111m	new piston and backing plate	109,300
69X31111m	new piston and backing plate	90,980
69X31111m	new piston and backing plate	101,320
69X31111m	new piston and backing plate	131,010
LO-251746	run using piston and plate listed	253,990

APPENDIX G. – EVALUATION OF SCPL CANDIDATES IN FZG TESTING

ASTM D 5182-97				
FZG Test to Evaluate Scuffing (Scoring)				
Load Capacity of Oils at 90°C				
Filename	FZGLoad_LO250033_03-0247_20100719.PDF	FZGLoad_LO251746_03-0248_20100720.PDF	FZGLoad_LO253071_03-0249_20100721.PDF	FZGLoad_LO254054_03-0250_20100721.PDF
Oil Code	LO250033	LO251746	LO253071	LO254054
Test No	03-0247	03-0248	03-0249	03-0250
EOT Date	7/19/2010	7/20/2010	7/21/2010	7/21/2010
Failure Load Stage	12	12	>12	9
Pre-Stage (12) Oil Temp (°C)	90	90	90	90
Post-Stage (12) Oil Temp (°C	139.2	132.9	132.2	119.5
Start of Test Date	7/19/2010	7/20/2010	7/21/2010	7/21/2010
End of Test Date	7/19/2010	7/20/2010	7/21/2010	7/21/2010
Gear Set Number	7753	7754	7755	7817
Gear Side	A	A	A	A
Average Speed (RPM)	1450	1450	1449.8	1450
Total Motor Revolutions (including coastdown)	261,000	261,000	260,964	195,750
Test Oil Temperature at End of Stage (°C)				
Stage 1	59.6	57.9	68.1	60
Stage 2	81.7	77.5	84.4	82.5
Stage 3	91.3	89.5	91.1	91.8
Stage 4	93	94.1	94	93.4
Stage 5	90.4	95.4	93.7	96.2
Stage 6	97.7	98	95.4	100
Stage 7	102.2	101.8	99.8	108.3
Stage 8	107.9	106	105.6	115.3
Stage 9	115.5	115.2	113.1	119.5
Stage 10	121.5	119.5	120.9	--
Stage 11	126.8	123.8	127.9	--
Stage 12	139.2	132.9	132.2	--
Gear Weight Data				
Pinion Weight (gms)				
Before	724.202	724.06	723.86	725.462
After	723.729	723.933	723.843	725.275
Loss	0.473	0.127	0.017	0.187
Gear Weight (gms)				
Before	1251.123	1254.983	1254.79	1261.68
After	1250.234	1254.753	1254.754	1261.327
Loss	0.889	0.23	0.036	0.353
Total (gms)				
Before	1975.325	1979.043	1978.65	1987.142
After	1973.963	1978.686	1978.597	1986.602
Loss	1.362	0.357	0.053	0.54
Post-Test Appearance of Each Gear Tooth				
Pinion				
Scratches	0	10	16	0
Scuffing	16	6	0	16
Total	16	16	16	16
Gear				
Scratches	0	15	24	0
Scuffing	24	9	0	24
Total	24	24	24	24
Comments	Medium wear and polishing on all pinion and gear teeth	Medium wear and polishing on 6 pinion teeth. Trace wear and polishing on 10 pinion teeth. Medium wear and polishing on 9 gear teeth. Trace wear and	Trace wear and polishing on all pinion and gear teeth	Medium wear and polishing on 16 pinion teeth. Medium wear and polishing on 24 gear teeth.

FZG ASTM D4998 Wear Test				
Filename	03-0251.pdf	03-0252.pdf	03-0253.pdf	03-0254.pdf
Test	FZG ASTM D4998 Wear Test	FZG ASTM D4998 Wear Test	FZG ASTM D4998 Wear Test	FZG ASTM D4998 Wear Test
Sponsor Code	LO250033	LO251746	LO253071	LO254054
Secondary Code	N/A	N/A	N/A	N/A
Test Type	D-4998	D-4998	D-4998	D-4998
SwRI Oil Code	LO-250033	LO-251746	LO-253071	LO-254054
Stand No	3	3	3	3
Test No	251	252	253	254
EOT Date	7/23/2010	7/25/2010	7/26/2010	7/27/2010
Hrs Completed	20	20	20	20
Amt wt loss	0.009	0.006	0.003	0.026
Gear Weight Data (g)				
Before				
Pinion	723.729	723.933	723.843	725.275
Gear	1250.234	1254.753	1254.754	1261.327
Total	1973.963	1978.686	1978.597	1986.602
After				
Pinion	723.722	723.927	723.838	725.263
Gear	1250.232	1254.753	1254.756	1261.313
Total	1973.954	1978.680	1978.594	1986.576
Loss				
Pinion	0.007	0.006	0.005	0.012
Gear	0.002	0.000	-0.002	0.014
Total	0.009	0.006	0.003	0.026
Post-Test Appearance of Each Gear Tooth				
Scratches				
Pinion	16	16	16	16
Gear	24	24	24	24
Total				
Pinion	16	16	16	16
Gear	24	24	24	24
Comments	Trace wear on all pinion teeth. Trace wear and light discoloration on all gear teeth.	Trace wear and light discoloration on all pinion teeth and all gear teeth.	Trace wear on all pinion teeth. Trace wear and light discoloration on all gear teeth.	Trace wear on all pinion teeth. Light wear and polishing on all gear teeth.

APPENDIX H. – GVSETS PAPER: EVALUATION OF SINGLE COMMON POWERTRAIN LUBRICANT (SCPL) CANDIDATES FOR FUEL CONSUMPTION BENEFITS IN MILITARY EQUIPMENT

2011 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
POWER AND MOBILITY (P&M) MINI-SYMPOSIUM
AUGUST 9-11 DEARBORN, MICHIGAN

Evaluation of Single Common Powertrain Lubricant (SCPL) Candidates for Fuel Consumption Benefits in Military Equipment

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ABSTRACT

The Single Common Powertrain Lubricant (SCPL) program is seeking to develop an all-season (arctic to desert), fuel-efficient, multi-functional powertrain fluid with extended drain capabilities. To evaluate candidate lubricants for the purpose of fuel consumption effects, a test cycle was developed using the GEP 6.5L(T) engine found in the HMMWV. Field data collected at Ft. Hood, TX was used to determine a set of speed, load and temperature points which could be reproduced consistently in test-cell operation. These points were condensed into a 14-mode cycle for use within the SCPL program. In addition to fresh condition oil, some lubricants were evaluated at end-of-life drain conditions to determine consumption effects over time. Results from the program indicated a significant fuel consumption benefit with lower viscosity lubricants when compared to current in-use military engine oils.

INTRODUCTION

The Single Common Powertrain Lubricant (SCPL) program goal is to develop an all-season (arctic to desert), fuel-efficient, multi-functional powertrain fluid with extended drain capabilities. This program utilizes state-of-the-art base oil and additive technologies to significantly improve upon current military engine and transmission lubricants and enable future powertrain technologies. Previous phases of the program demonstrated the technical and economic feasibility of the low viscosity SCPL concept [1]. In the current phase, lessons learned from the technical feasibility study are being used to guide the development of candidate SCPLs. This paper outlines the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) development of a method to discriminate SCPL candidate lubricants on the basis of fuel consumption. Two distinct groups exist in dynamometer engine fuel consumption test procedures: standardized test procedures, and industry-accepted or developmental test procedures. Many of the available test procedures are more applicable to light-duty diesel applications than heavy duty diesel applications, and specific fuel consumption engine dynamometer standardized test procedures for heavy-duty diesel engines are thus far non-existent. This is likely due to the focus on extended engine durability, emphasis of emissions reductions, and exhaust aftertreatment development that is currently driving

research within the heavy-duty diesel industry. Another option for heavy-duty diesel fuel consumption testing is an in-vehicle method such as the SAE J1321 test; however, this is a very cost- and labor-intensive choice [2].

APPROACH

Current technology for evaluation of engine oil fuel efficiency is represented by standardized laboratory test procedures, including CEC L-54-T-96 M111, ASTM D6873 Sequence VIB, and Sequence VID. None of these tests, however, provide a proper representation for military vehicle applications. To create a test representative of actual vehicle use, a High Mobility Multipurpose Wheeled Vehicle (HMMWV) at Ft. Hood, TX was instrumented through two multi-week training missions [3]. Oil temperature, engine speed, vehicle speed, and throttle position were recorded. This collected data set was used to define 26 distinct load, speed, and temperature points. These points were then replicated on a dynamometer test stand. An image of the stand is shown in Figure 1.

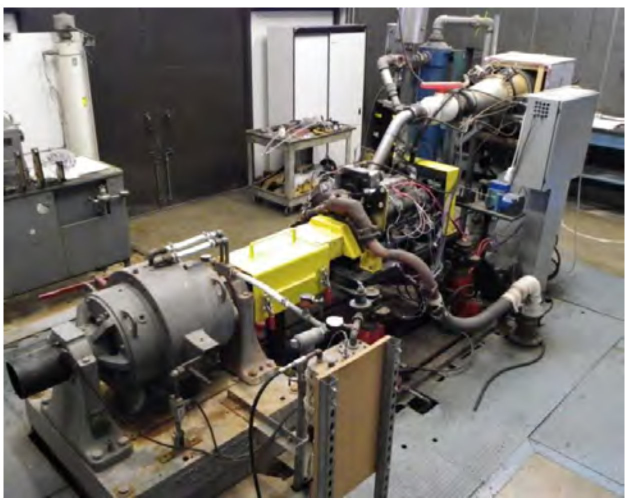

Figure 1: 6.5L(T) Dynamometer Test Stand

Fuel inlet temperature and inlet air temperature were maintained at a constant 95°F and 75°F respectively. JP8 was used as the test fuel throughout the entire project. Coolant and oil temperatures were controlled at increasing values from step to step. An SAE 40 weight oil was used as the baseline lubricant for test development. Each point was operated for 15 minutes to ensure stabilization prior to data collection. Figure 2 shows the test points in relation to a wide-open throttle torque curve. While only 21 load-speed points appear in the figure, some are repeated at multiple engine oil temperatures.

After multiple repetitions of the cycle, it was determined that a simplified cycle would increase the rate at which oils could be evaluated and improve the repeatability of the test in TFLRF facilities. From the 26 points, duplicate speed and load points were eliminated and steps were ordered for increasing oil temperature during the test. Two steps were added for high-speed, high-load conditions at the elevated oil temperature. A summary of the revised test cycle is shown in Table 1 with graphical representation in Figure 3, which compares the fuel consumption cycle to a wide-open throttle torque curve. The line connecting the points indicates the order in which they were run, starting with 1100 RPM and 59.7 ft-lbs of torque.

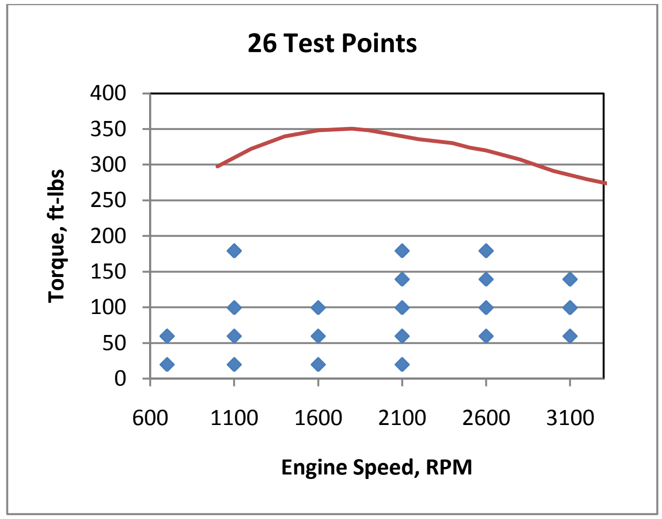

Figure 2: Original Test Points

Table 1: 14 Point Test Cycle

Point	RPM	Torque, ft-lbs	Power, hp	Oil Sump, ˚F
1	1100	59.7	12.5	165
2	2100	59.7	23.9	180
3	1100	99.6	20.9	
4	1100	179.2	37.5	
5	1600	99.6	30.3	195
6	2100	139.4	55.7	
7	2600	99.6	49.3	215
8	2100	179.2	71.7	
9	3100	99.6	58.8	
10	2600	139.4	69.0	
11	3100	139.4	82.3	245
12	2600	179.2	88.7	
13	2400	302.4	138.2	
14	2800	250.8	133.7	

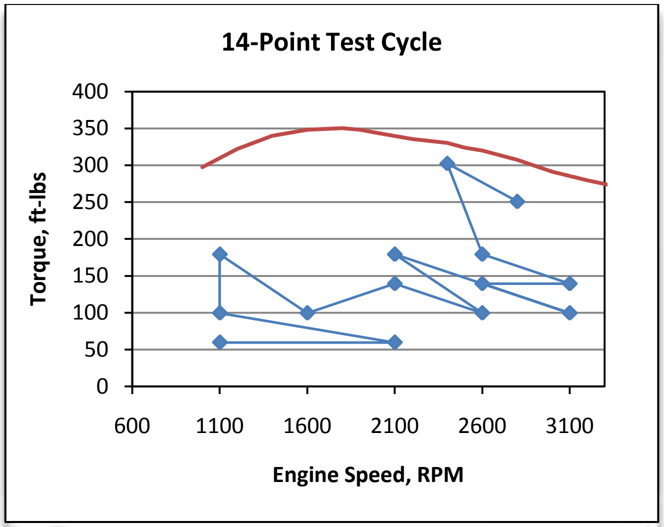

Figure 3: 14-Point Test Cycle

Out of the 15 minute run time for each step, data from the last five minutes was used to determine a step Brake Specific Fuel Consumption (BSFC) value. The BSFC value was then weighted based on the fuel flow rate at each step, with high flow rates receiving a higher weighting factor. The weighting factor for each step is shown in Table 2. The weighting factors were developed through the SAE 40 oil testing, but remained unchanged for other lubricants.

Table 2: BSFC Weighting Factors

Step	Weighting Factor
1	0.02
2	0.04
3	0.03
4	0.04
5	0.04
6	0.06
7	0.07
8	0.07
9	0.09
10	0.09
11	0.11
12	0.1
13	0.13
14	0.14

The weighted values were summed to produce a cycle BSFC value. Each oil was run seven times to obtain results for statistical analysis. Results from a complete SAE 40 oil test are shown in Table 3.

Table 3: SAE 40 BSFC Results

SAE 40		
	Fuel Used, gal	BSFC, lb/hp-hr
Run 1	15.7	0.4960
Run 2	15.75	0.4972
Run 3	15.77	0.4970
Run 4	15.68	0.4945
Run 5	15.62	0.4921
Run 6	15.65	0.4934
Run 7	15.7	0.4949
Average	15.70	0.4950
Std. Dev.	0.05	0.0019
COV	0.33%	0.38%

A MIL-PRF-21260 SAE 10W oil was used to evaluate the procedure's ability to discriminate between fluids. The fluids showed a significant difference (3.08%) in BSFC, as shown in Table 4.

Table 4: Fuel Consumption Changes: SAE 40 to SAE 10W

	Run	Cycle BSFC
SAE 40	1	0.4960
	2	0.4972
	3	0.4970
	4	0.4945
	5	0.4921
	6	0.4934
	7	0.4949
	Average	0.4950
	Standard Deviation	0.0018
	COV	0.38%
MIL-PRF-21260 SAE 10W	1	0.4810
	2	0.4804
	3	0.4802
	4	0.4799
	5	0.4809
	6	0.4793
	7	0.4775
	Average	0.4798
	Standard Deviation	0.0012
	COV	0.25%
	Percent Change: SAE 40 to SAE 10W	3.06%

To evaluate long-term repeatability, the SAE 40 oil used in development of the test was run multiple times. Over a six-month period the engine showed an engine drift in the average BSFC of 0.24% using the same batch of SAE 40 oil. This change was not statistically significant at a 95%

confidence interval and indicated the engine to be an effective method for testing fuel consumption changes from SCPL candidates and other lubricating oils. The comparative results from the two tests are shown in Table 5.

Table 5: Fuel Consumption Changes: Test Stability

	Run	Cycle BSFC
SAE 40 Run 1	1	0.4960
	2	0.4972
	3	0.4970
	4	0.4945
	5	0.4921
	6	0.4934
	7	0.4949
	Average	0.4950
	Standard Deviation	0.0018
	COV	0.38%
SAE 40 Run 2	1	0.4980
	2	0.4946
	3	0.4925
	4	0.4935
	5	0.4960
	6	0.4912
	7	0.4909
	Average	0.4938
	Standard Deviation	0.025
	COV	0.52%
Percent Shift Over Six-Month Period		0.24%

SCPL CANDIDATE TESTING

For the purpose of testing SCPL candidates, a new engine was built and installed in the test cell. A run-in process of 100 hours was conducted on the engine followed by back-to-back fuel consumption tests to indicate if stability had been reached. Results from this test are shown in Table 6. The shift in Cycle BSFC value was not statistically significant.

Table 6: Fuel Consumption changes: Engine Break-In

	Run	Cycle BSFC
New Engine SAE 40 Run 1	1	0.5131
	2	0.5147
	3	N/A
	4	0.5108
	5	0.5150
	6	0.5108
	7	0.5111
	Average	0.4950
	Standard Deviation	0.0018
	COV	0.38%
New Engine SAE 40 Run 2	1	0.5152
	2	0.5130
	3	0.5142
	4	0.5148
	5	0.5140
	6	0.5145
	7	0.5139
	Average	0.5142
	Standard Deviation	0.0007
	COV	0.14%
Percent Shift After Break-In		-0.32%

Throughout the project, the baseline oil was run prior to each candidate lubricant to account for shifts in engine performance. In addition to the fuel consumption benefit from fresh oil, selected lubricants were tested at the end of useful life to determine the indicated fuel consumption benefit at the time of drain. Following the evaluation of fresh oil, the end-of-test (EOT) drain from SCPL endurance tests was placed in the engine and an additional seven-cycle test was conducted. These EOT oils ran from between 140 and 168 hours of the Tactical Wheeled Vehicle Cycle to break the oil. Testing was performed based on the condition of the EOT oil and deemed unsuitable for some candidate lubricants. Table 7 shows the change in fuel consumption between each candidate lubricant and the baseline SAE 40 oil. All results shown were statistically significant shifts. In addition to experimental lubricants, two commercially available products were evaluated for comparison.

Table 7: Candidate Lubricant Test Results

Lubricating Oil	% Improvement Fresh	% Improvement EOT
MIL-PRF-2104G SAE 15W-40	0.83	N/A
MIL-PRF-2104H SAE 15W-40	0.86	N/A
MIL-PRF-46167 OEA-30 (Batch 1)	2.27	1.26
MIL-PRF-46167 OEA-30 (Batch 2)	2.38	N/A
Experimental Arctic Oil 1	2.51	2.01
Experimental Arctic Oil 2	2.51	N/A
Experimental SAE 0W-20	2.41	1.83
Experimental SAE 0W-30	2.00	0.37
Commercial SAE 15W-40	0.27	-2.14
Commercial SAE 5W-40	0.36	N/A
Experimental Tractor Oil	1.54	N/A

CONCLUSIONS

The use of low viscosity engine oil was shown to have a significant impact on fuel consumption. Additionally, the difference between the current MIL-PRF-2104H SAE 15W-40 grade and the best experimental fluid had an improvement of 1.66% over the test cycle. This value is not far from a 1.5% improvement previously seen in SAE J1321 testing with MIL-PRF-2104G SAE 15W-40 grade and an early candidate oil [4]. Although the J1321 testing was conducted in vehicles, on a different drive cycle, with a different engine and uncontrolled temperatures, the similarity in results is encouraging. Even at end-of-life conditions, three of the four low viscosity oils available showed an improvement over the currently used product. While improvements of this magnitude may not be noticeable with a single vehicle, the potential exists for substantial fuel savings when applied over the entire ground vehicle fleet.

REFERENCES

[1] Brandt, A., Comfort, A., Frame, E., Hansen, G., Villahermosa, L., Warden, R. and Yost, D., “Feasibility of Using Full Synthetic Low Viscosity Engine Oil at High Ambient Temperatures in Military Vehicles”, SAE Technical Paper 2010-01-2176, 2010, dio:10.4271/2010-01-2176.

[2] Joint TMC/SAE Fuel Consumption Test Procedure – Type II, J1321, 1986.

[3] Frame, E. and Yost, D. (2006, July). *HMMWV Field Operation Data Collection and Analysis* (Publication No. ADA449160). Retrieved from Defense Technical Information Center Online: www.dtic.mil.

[4] Brandt, A., Comfort, A., Villahermosa, L. and Warden, R., “Fuel Efficiency Effects of Lubricants In Military Vehicles,” SAE Technical Paper 2010-01-2180, 2010, dio:10.4271/2010-01-2180. .

APPENDIX I. – GEP 6.5L(T) TEST FUEL

Test Fuel Description:

Fuel used for engine durability and fuel consumption testing was blended on site from commercially available Jet-A. To ensure that fuel lubricity impacts would have a minimized role on fuel system degradation resulting in reduced engine performance, a double max treat rate of lubricity additive DCI-4A was used during blending. The remaining two additives utilized in JP8, anti-icing and anti-static, were not used in the test fuel blend, as they have little to no impact on the fuel used in this application. Table I1 below shows the certificate of analysis (COA) for the Jet-A as purchased for blending. Table I2 shows the resulting fuel lubricity values after the double max treat rate of DCI-4A was successfully blended into the test fuel.

Table I1 – JET-A Certificate of Analysis

Alcor PetroLab, L.L.P.

20 Laboratory Road, Floresville, Texas 78114 Telephone 830-216-3113 www.alcorpetrolab.com

NuStar
San Antonio Products Terminal
P. O. Box 241017
San Antonio, Texas 78224-1017

February 22, 2010

Sample Type: Jet A
Tank Number.: 103
nt @ 1600 02/21/10 pu @ 0600 02/22/10

Sample Date: 02/22/10
Sample Time: 630

Volatility	Method	Specification		Result
Initial Boiling Point (°F)	D 86			320.0
Distillation 10% Rec (°F)		400	max	334.4
Distillation 50% Rec (°F)		Report		365.9
Distillation 90% Rec (°F)		Report		415.4
Distillation 95% Rec (°F)		Report		433.4
Distillation Final BP (°F)		572	max	459.5
Distillation Recovery (vol %)				98.9
Distillation Residue (vol %)		1.5	max	0.9
Distillation Loss (vol %)		1.5	max	0.2
Flash Point, Tag Closed (°F)	D 56	100	min	121.0
API Gravity @ 60 (°F)	D 1298	37.0 / 51.0		45.8
Cetane Index	D 4737	40.0	min	41.3
Particulate Matter Mgs/Gal	D 2276	3.0	max	0.8
Sulfur Wt %	D 7220	0.30	max	0.0001
Copper Strip	D130	No. 1	max	1A
Existent Gum Mgs / 100 Mls.	D381	7	max	<1.0
Fluidity				
Freezing Point (°F)	D 2386	-41.0	max	-76.9
Contaminants				
Color (Saybolt)	D 156	+15	min	+30
Appearance	D4176	clear/bright	pass/fail	Pass
Water Reaction: Change	D 1094	2.0	max	0
Water Reaction: Interface Rating	D 1094	2	max	1
Water Reaction: Separation Rating	D 1094	2	max	1
MSEP	D 3948	85	min	99

This Product Conforms to ASTM D1655 for the Above Tests: XX YES ____ NO

Reviewed and submitted by,

Chris Taylor CEO

Report Number: P022210A

Table I2 – JET-A Lubricity Test Results

Property	ASTM	Result
Scuffing Load BOCLE	D6078	3450
BOCLE	D5001	0.5
HFFR	D6079	0.69